XXIV INTERNATIONAL PHYSICS OLYMPIAD

WILLIAMSBURG, VIRGINIA

JULY 10 - 18, 1993

A project of the
American Association of Physics Teachers,
assisted by the American Institute of Physics

ARTHUR EISENKRAFT, EDITOR

ation

AMERICAN INSTITUTE OF PHYSICS

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June 10, 1994

Defense Technical Information Center
Building 5, Cameron Station
Alexandria, VA 22314

Re: Grant Number N00014-93-1-0270

To Whom It May Concern:

Attached is a copy of the Proceedings of the XXIV International Physics Olympiad held in Williamsburg, VA on July 10 - 18, 1993. Other copies are being sent to the Scientific Officer (3) and to the Grant Administrator (1) as stipulated in ATTACHMENT NUMBER 1 to the grant document # N00014-93-1-0270.

The American Institute of Physics, and the students and coaches of the United States Physics Olympiad Team, are most appreciative of the financial assistance provided by the Office of Naval Research. These monies allowed the United States Team to adequately prepare and participate in the XXIV International Physics Olympiad. All members of the U. S. Team earned awards for their performance in the competition.

Thank you.

Sincerely,

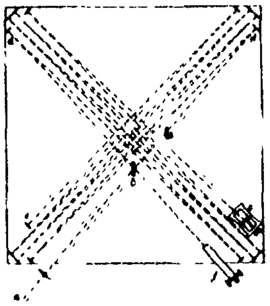
Donald F. Kirwan

enc.

XXIV INTERNATIONAL PHYSICS OLYMPIAD

WILLIAMSBURG, VIRGINIA

JULY 10 - 18, 1993



EDITOR:
ARTHUR EISENKRAFT
FOX LANE HIGH SCHOOL
BEDFORD, NY 10506
UNITED STATES

XXIV International Physics Olympiad

To Kaila, Michael, Noah and my Mother

CONTENTS

PREFACE

The XXIV International Physics Olympiad was a celebration of academic excellence. The event took place in the United States of America in the town of Williamsburg, Virginia during the week of July 10 - 18, 1993. This year was the first opportunity for the United States to host this prestigious event. The organization of the Olympiad was under the auspices of the American Association of Physics Teachers, with assistance from the American Institute of Physics. Forty one countries (201 students) participated in the XXIV IPhO and an additional four countries sent official observers, making this the largest Olympiad ever.

The focus and raison d'être of the Olympiad is the examination. It must be able to challenge the very best students in the world. The five hour theoretical exam must have problems (traditionally, three problems) that span the syllabus of the IPhO. The five hour experimental exam may have one or two problems that require a laboratory sophistication that we associate with our best university students. Two years before the XXIV IPhO, I asked Professor Anthony P. French of Massachusetts Institute of Technology if he would accept the responsibility of creating, field testing, administering and grading the exams. The success of the Olympiad is due to the care and commitment that he brought to these tasks. After assembling a committee of six talented physicists, we devoted an entire year (up until the last week) defining and refining the problem sets. The committee's concerted effort paid off when the international collection of team leaders gave the problems high marks for comprehensiveness and creativity. The examination is also the main legacy of the Olympiad. Every year, tens of thousands of students aspiring for a place on their nation's Olympiad team will study these problems.

The exam committee was joined by an additional twenty-five professors for the grading of the exams. These dedicated physicists pored over the student papers (written in twenty nine languages), and then arbitrated the grades with the team leaders from the forty one nations. The exam committee and graders represented thirty five institutions and in that way showed that interest in pre-college education is quite widespread in the United States.

The Olympiad required a locale that could acquaint our special guests with cultural, scientific and recreational activities. The College of William & Mary in Williamsburg, Virginia, satisfied all of our needs. Cultural outlets range from the Colonial Williamsburg restoration and the college, which was

celebrating its 300th anniversary, to the local community itself. The community was sufficiently cosmopolitan that when we arranged for each of the team leaders to spend an evening in a nearby home, every host family had some connection with the homeland of its visitors. Scientific activities included tours of the Continuous Electron Beam Accelerator Facility (CEBAF) in Newport News, Virginia, and the NASA Langley Research Center in Hampton, Virginia, with its wind tunnels, and F-15 fighter aircraft. For recreation we planned a refreshing afternoon at Water Country USA (what better release after a five-hour physics exam?), a day at the Busch Gardens amusement park and Duracell's day at Virginia Beach. Moreover, we had at the College of William & Mary two exceptional local coordinators — Hans von Baeyer and Roy Champion, both of the physics department, who provided the hospitality and attention to details that makes an Olympiad successful. The College of William & Mary was the perfect location for the Olympiad because Hans and Roy were there!

Physics activities were not restricted to sitting at tables solving theoretical problems or teasing out nature's secrets at lab benches. The students and their team leaders were also entertained by physics demonstration shows: Richard Berg of the University of Maryland gave his physics IQ test, which delightfully uncovered some misconceptions of the Olympiad students, their leaders, and other guests; Dick Minnix and Rae Carpenter of Virginia Military Institute got the participants to sit on nails appear to fly (it's done with mirrors) and view music on soap bubbles; Loren Winters of the North Carolina School of Science and Mathematics showed how strobe photography can entertain and teach us about what happens in times too quick for our visual system. Many of the leaders from the visiting nations took copious notes and were excited about how they might use some of these ideas to introduce physics in their own countries. In addition, Jack Wilson (Rensselaer Polytechnic Institute) introduced everybody to the cutting edge of the educational use of computers. Students were able to get a hands on workshop opportunity to merge videodisc, microcomputer based labs and computers. (This was accomplished when Jack was not busy with our network of computers required to translate the exams into 30 languages or getting the databases prepared. For these tasks, Wilson was assisted by Jim Wynne (IBM Watson), friend of the Olympiad and of science education, and Eric Bluntzer and David McKenna (RPI).) We also had the physics of roller coaster rides at Busch Gardens and the paper olympics.

The Busch Gardens day and paper olympics evening served an additional purpose — to force an interaction amongst the students from different nations. At Busch Gardens, mixed teams were set up (e.g. 1 Bulgarian, 1 Thai, 1 German, 1 Canadian and 1 Cuban). Busch arranged for the park to open three hours early so that our Olympiad guests would have no lines and ample

opportunity to use their force meters, stopwatches and calculators to take measurements and analyze the three roller coasters. Many high schools have programs where students analyze the amusement park rides. We needed something more and David Wright (Tidewater Community College, VA) and Barbara Wolff-Reichert (Livingston High School, NJ) were able to write more challenging problems for the world's finest physics students. Busch then hosted a barbecue where we were able to reward the top teams with T-shirts and other memorabilia.

The paper olympics had similar mixed teams working together to form the strongest structure from a piece of paper, the tallest structure from a piece of paper, and the slowest descent structure made from newspaper - lots of newspaper. This fun, interactive evening was led by Donna Berry Connor and assisted by twenty high school teachers in attendance at CEBAF for a teacher enhancement program. (Beverly Hartline of CEBAF was instrumental in getting these teachers to be a part of the Olympiad.)

More community building took place at our College Deli night where all students wore a college T-shirt (donated by 42 institutions) and ate pizza and subs. For entertainment we had a karioke machine (it supplies music and lyrics on video) while participants sing along. Students who had seemed rather reserved most of the week managed to come alive with microphone in hand. The hit songs of the evening were "La Bamba" performed by the Cubans and Mexicans and my only public rendition of "Twist and Shout." The night before the closing ceremony we had an "American night," with jazz and bluegrass music. Patricia Rourke of St. Stephen's and St. Agnes School in Alexandria, Virginia, choreographed the American night, the opening and closing ceremonies, and more.

It was essential to have guides for the Olympiad students. The five students from each country were assigned one guide, who was responsible for acclimating them to the US as well as shepherding them to the activities. Karen Berquist (College of William & Mary) and Lynn Carlson (Darien Public Schools, CT) kept tabs on all of the guides. Most of the guides were from the local area. They included graduate students, undergraduates and teachers. Ten guides were former US Olympiad team members. This formed a special reunion of sorts and provided us with a base of people who knew about Olympiad emotions. Among these was 1992 gold medalist Eric Miller, now a student at Harvard. Miller spoke eloquently at the Opening Ceremony. As a guide for the Swedish team, Eric found it strange to see the event from another angle, without the pressure of the exams or the attention of the press.

Olympiads require invitations, arrival times, hotel accommodations and meals. Yvette Van Hise (High Technology HS, NJ) devoted many months to letters, phone calls, faxes and e-mails to insure that the 41 countries acquired the necessary visas, appropriate airline flights, health forms and a sincere

welcome to the upcoming event. During the Olympiad, Yvette was able to personalize these international relationships as she registered all teams and helped with exam preparation. Delores Mason (AAPT) did an extraordinary job from accompanying me on the first site visit to the selection and contracting of hotels, dormitory space, airport buses, and all meals. She was ably assisted by her office colleagues, Maria Elena Khoury and Carol Heimpel (AAPT). The night of translation and exam copying required the assistance of James Stith (US Military Academy), John Carlson (Fox Lane High School, NY), Jack Hehn and Bernard V. Khoury (AAPT).

Leon Lederman, who was the chair of the XXIV IPhO, spoke at both the opening and closing ceremonies. The opening ceremony featured the Fife and Drum Corps of Williamsburg followed by a flag bearer from each of the nations, thus blending national pride with international goodwill. The closing ceremony included classical guitar and flute and an *a capella* performance of "The Star Spangled Banner." The highlight of the closing ceremony was the awarding of medals to the students by Nobel Laureates Lederman, Jerome I. Friedman and Val Fitch.

The banquet following the closing ceremony traditionally includes a rendition of "Waltzing Matilda," by the Australian students. We tried to begin a new tradition by asking the students from each team to perform a folk song. The effort was a tremendous success. The Czechs and Slovaks sang together and drew loud applause from everyone. The final song started with a group of 15 Olympiad students from different nations singing "We are the World." In an impromptu manner, students from the audience began to converge on the stage to join in. Before long, the students from all 41 nations were crowded onstage, waving miniature flags and singing. It was a moving finale to the XXIV Olympiad: We had succeeded in building a sense of community. We had moved the world a little bit forward.

An event of this magnitude requires substantial financial resources. Ken Ford and his staff at AIP helped raise funds with assistance from Bernard Khoury and Jim Stith. Don Kirwan of AIP was the financial hero of the Olympiad. He was able to persuade both the National Science Foundation and the Department of Education that support of the Olympiad was important and worthwhile. Other generous support came from Duracell, IBM and AT&T and I am grateful to the specific people from these companies who were so helpful. The entire physics community, through the member societies of AIP, physics research facilities, and individuals provided another layer of financial backing. The in-kind support of many companies allowed the Olympiad to have additional benefits as already described as well as gifts for the participants to take home.

The preparation and execution of the Olympiad required the cooperation and assistance of many people. The science department at Fox Lane and the

entire Bedford Public School community were able to support me in this endeavor. They were kind and understanding and expressed interest during the two years of planning. A long list of "special thanks" is found in these proceedings. The names of these individuals should not be glossed over. Each made an important contribution to the Olympiad and each is responsible for the Olympiad's success.

The intensity of the actual Olympiad week outshines any other event I have been involved in. The power and passion created a bond of friendship with members of the organizing committee and our assistants that will reach far into the future. I depended on so many people during the Olympiad and I was rewarded with their energy, their friendship and their goodwill. My life has been enriched by the Olympiad more than I had ever imagined.

A special thanks goes to my wife, Kaila, and my boys, Michael and Noah. I was so happy they could share the Olympiad with me. Although I was able to see them less than an hour a day, having them near was crucial for me. My family is my life, and the foundation of everything I do.

For the organizers, the XXIV International Physics Olympiad was a week of no sleep; but in a way, it was also a week of dreams. I hope that these proceedings provide a portrait of those dreams.

Arthur Eisenkraft

Arthur Eisenkraft

PART 1

XXIV International Physics Olympiad

Honorary Board and Organizing Committee

Chair: Leon Lederman
Illinios Institute of Technology, Nobel Laureate, 1988

Executive Director: Arthur Eisenkraft
Bedford Public Schools, New York

Honorary Board

John A. Armstrong
IBM Corporation

Nicolaas Bloembergen
Harvard University
Nobel Lauteate, 1981

Val Fitch
Princeton University
Nobel Laureate, 1980

Kenneth W. Ford
American Institute of Physics

Sheldon Lee Glashow
Harvard University
Nobel Laureate, 1979

Arno Penzias
AT&T Bell Laboratories
Nobel Laureate, 1978

Melba Phillips
University of Chicago

Kenneth G. Wilson
Ohio State University
Nobel Laureate, 1982

Organizing Committee

Arthur Eisenkraft (Chair), *Bedford Public Schools, New York*
Hans von Baeyer, *The College of William and Mary*
Roy L. Champion, *The College of William and Mary*
Anthony P. French, *Massachusetts Institute of Technology*
Bernard V. Khoury, *American Association of Physics Teachers*
Delores Mason, *American Association of Physics Teachers*
Patricia Allen Rourke, *St. Stephen's & St. Agnes School, Virginia*
Yvette Van Hise, *High Technology High School, New Jersey*
Jack M. Wilson, *Rensselaer Polytechnic Institute*
Joan Wrather, *American Institute of Physics*

Additional Committees

Academic Committee

Chair: Anthony P. French, *Massachusetts Institute of Technology*

Session Chair of the International Board: Judy Franz, *University of Alabama*

Ralph Baierlein. *Wesleyan University*
Peter John Collings, *Swarthmore College*
Richard J. Duffy, *Newton North High School, Massachusetts*
Peter Heller, *Brandeis University*
Charles H. Holbrow, *Colgate University*
Marvin L. Marshak, *University of Minnesota*

Guide Committee

Co-Chairs: Karen Berquist, *The College of William and Mary*
Lynn Carlson, *Darien Public Schools, Connecticut*

Financial Committee

Kenneth W. Ford, *American Institute of Physics*
Tim Kachinske, *American Institute of Physics*
Bernard V. Khoury, *American Association of Physics Teachers*
Donald F. Kirwan, *American Institute of Physics*
James Stith, *US Military Academy*

GRADING TEAMS

Theory Problem #1
Leader: A.P. French
Other Graders: Ronald D. Edge, *University of South Carolina*
Edwin Goldin, *A.I.P. (Washington D.C)*
Edwin R. Jones, *University of South Carolina*
Lewis Slack, *A.I.P. (retired)*
Francis M. Tam, *Frostburg State University*

Theory Problem #2
Leader: Charles H. Holbrow
Other graders: Isaac D. Abella, *University of Chicago*
William E. Cooke, *U.C.L.A.*
Steven C. Frautschi, *California Institute of Technology*
Peter D. Parker, *Yale University*
Carl H. Poppe, *Lawrence Livermore Laboratory*

Theory Problem #3
Leader: Marvin Marshak (for Ralph Baierlein)
Other graders: Nelson Christianson, *University of Minnesota*
Hans Courant, *University of Minnesota*
David J. Griffith, *Reed College*
Nathaniel P. Longley, *Carleton College*
Howard W. Nicholson, Jr., *Mount Holyoke College*

Experimental Problem #1
Leader. Peter Collings
Other graders: Rexford E. Adelberger, *Guilford College*
Joel E. Gordon, *Amherst College*
Lee L. Larson, *Denison University*
Mary L. Lowe, *Loyola College, Baltimore*
John B. VanZytveld, *Calvin College, Michigan*

Experimental Problem #2
Leader: Peter Heller
Other graders:* Leslie F. Brown, *Connecticut College*
Eric S. Jensen, *Brandeis University*
Wayne Lewis, *St. John Fisher College, NY*
George Zimmerman, *Boston College*

*Dr Noreen Jensen (Brandeis University) was to have been the sixth grader in this team but was unfortunately unable to participate

Participating Delegations

Australia
Austria
Belgium
Bulgaria
Canada
China
Colombia
Croatia
Cuba
Cypress
Czech Republic
Estonia
Finland
Germany
Greece
Hungary
Iceland
Indonesia
Iran
Italy
Kuwait
Lithuania
Mexico
Netherlands
Norway
Philippines
Poland
Republic of Korea
Romania
Russia
Singapore
Slovakia
Slovenia
Spain
Suriname
Sweden
Thailand
Turkey
Ukraine
United Kingdom
United States of America
Vietnam

Observing Delegations

Argentina
Israel
Portugal
Taiwan

Sponsors

The XXIVth International Physics Olympiad offers a special thank you to the following for their generous support.

Principal Sponsor

National Science Foundation

Sponsors

Duracell
U.S. Department of Education
IBM Corporation
AT&T Foundation*
American Institute of Physics
American Association of Physics Teachers

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Optical Society of America

Contributors

The Society of Rheology
American Association of Physicists in Medicine
BP America
American Crystallographic Association
William Lehrfeld
American Astronomical Society
Vernier Software

*Support designated for the United States Olympiad Team

Generous In-Kind Support

Busch Gardens
PASCO Scientific
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Duracell
Ohaus Corporation
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CEBAF
NASA
Microsoft Corporation
Springer-Verlag New York, Inc.
Master Magnetics, Inc.

Additional Support

The College of William and Mary
Bedford Public Schools, New York
Brandeis University
Colgate University
High Technology High School, New Jersey
Massachusetts Institute of Technology
Newton North High School, Massachusetts
Rensselaer Polytechnic Institute
St. Stephen's & St. Agnes School, Virginia
Swarthmore College
University of Maryland, College Park
University of Minnesota
Wesleyan University

The XXIVth International Physics Olympiad offers
warmest thanks to these individuals
who contributed to this effort.

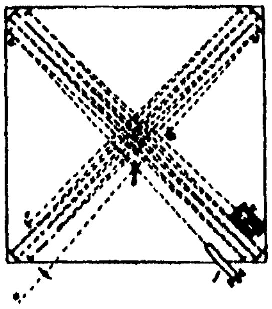
Richard E. Berg
Doris Bethel
Eric Bluntzer
Cecelia Brescia
Carl Brown
John Carlson
Rae Carpenter
Donna Berry Connor
John David Conrod
George Dewey
Beverly Hartline
Carol Heimpel
David Issing
Maria Elena Khoury
Harold Lefcourt
Candi Madgwick
David McKenna
Richard Minnix
Tom Penney
William Pollock
Shawn Reynolds
Lea Reich
Bryan Rourke
Szymon Rusinkiewicz
Diane Sellinger
Srinivasen Seshan
Cliff Shepperd
James Stith
Jody Sullivan
Ann Van Hise
Crystal Van Hise
Roger Van Hise
Madelynn Whitehead
Watkinson
Loren Winters
Barbara Wolff-Reichert
David Wright
Jim Wynne

Appreciation is also extended for the following
institutions for donations of
collegiate T-shirts.

Arizona State University
California State Polytechnic University, Pomona
California Institute of Technology
Case Western Reserve University
Clark University, Atlanta
Dickinson College
Drew University
Frostburg State University
Guilford College
Hampden-Sydney College
Hampton College
Indiana University
Indiana University of Pennsylvania
Kansas State University
Los Angeles Valley College
Massachusetts Institute of Technology
Mississippi State University
Montclair State College
Montana State University
Nebraska Wesleyan College
New Jersey Institute of Technology
North Carolina State University
Princeton University
Rensselaer Polytechnic Institute
Roanoke College
Rutgers, the State University of New Jersey
The College of William and Mary
The Ohio State University
The Pennsylvania State University
United States Military Academy
University of Alabama, Huntsville
University of Chicago
University of Maryland, College Park
University of Minnesota
University of Oregon
University of The Pacific
University of Washington
Vassar College
Virginia Military Institute
Virginia Polytechnic Institute and State University
Westminster College
Williams College

THE MICHELSON INTERFEROMETER

The logo design of the XXIV International Physics Olympiad is a reproduction of the sketch of the Michelson Interferometer as depicted in the November,



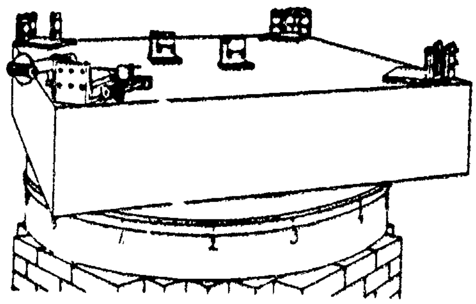
1887 issue of The American Journal of Science. It appears in the historic article, "On the Relative Motion of the Earth and the Luminiferous Ether," by Albert A Michelson and Edward W. Morley, in which they reported no success in detecting the motion of the earth through the ether. This "failure" was later seen as convincing evidence for Einstein's special theory of relativity (1905). (Two pages of this historic article are reprinted on the next page)

Albert A. Michelson was the first American to be awarded the Nobel Prize in Physics (1907). During his career, Michelson measured the International Meter in Paris with the wavelength of a cadmium spectral line as a standard; he was the first person to measure the angular diameter of a star (other than the Sun!); and he measured the speed of light with ever increasing accuracy. It is our privilege to commemorate Michelson as the United States hosts the International Physics Olympiad for the first time.

The first named difficulties were entirely overcome by mounting the apparatus on a massive stone floating on mercury; and the second by increasing, by repeated reflection, the path of the light to about ten times its former value.

The apparatus is represented in perspective in fig. 3, in plan in fig. 4, and in vertical section in fig. 5. The stone *a* (fig. 5) is about 1·5 meter square and 0·3 meter thick. It rests on an annular wooden float *bb*, 1·5 meter outside diameter, 0·7 meter inside diameter, and 0·25 meter thick. The float rests on mercury contained in the cast-iron trough *cc*, 1·5 centimeter thick, and of such dimensions as to leave a clearance of about one centimeter around the float. A pin *d*, guided by arms *gggg*, fits into a socket *e* attached to the float. The pin may be pushed into the socket or be withdrawn, by a lever pivoted at *f*. This pin keeps the float concentric with the trough, but does not bear any part of the weight of the stone. The annular iron trough rests on a bed of cement on a low brick pier built in the form of a hollow octagon.

3.

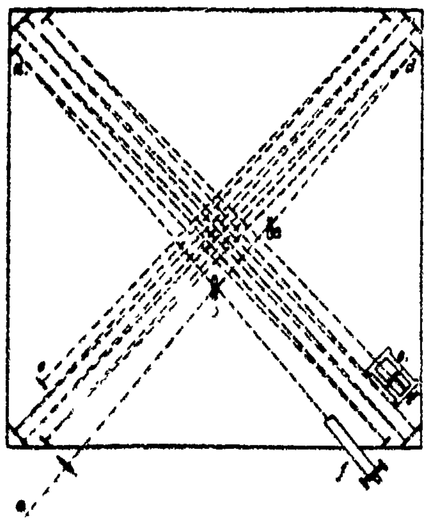


At each corner of the stone were placed four mirrors *dd ee* fig. 4. Near the center of the stone was a plane-parallel glass *b*. These were so disposed that light from an argand burner *a*, passing through a lens, fell on *b* so as to be in part reflected to d_1; the two pencils followed the paths indicated in the figure, *bdedbf* and $bd_1e_1d_1bf$ respectively, and were observed by the telescope *f*. Both *f* and *a* revolved with the stone. The mirrors were of speculum metal carefully worked to optically plane surfaces five centimeters in diameter, and the glasses *b* and *c* were plane-parallel and of the same thickness, 1·25 centimeter;

their surfaces measured 5·0 by 7·5 centimeters. The second of these was placed in the path of one of the pencils to compensate for the passage of the other through the same thickness of glass. The whole of the optical portion of the apparatus was kept covered with a wooden cover to prevent air currents and rapid changes of temperature.

The adjustment was effected as follows: The mirrors having been adjusted by screws in the castings which held the

4.



mirrors, against which they were pressed by springs, till light from both pencils could be seen in the telescope, the lengths of the two paths were measured by a light wooden rod reaching diagonally from mirror to mirror, the distance being read from a small steel scale to tenths of millimeters. The difference in the lengths of the two paths was then annulled by moving the mirror e_1. This mirror had three adjustments; it had an adjustment in altitude and one in azimuth, like all the other mirrors,

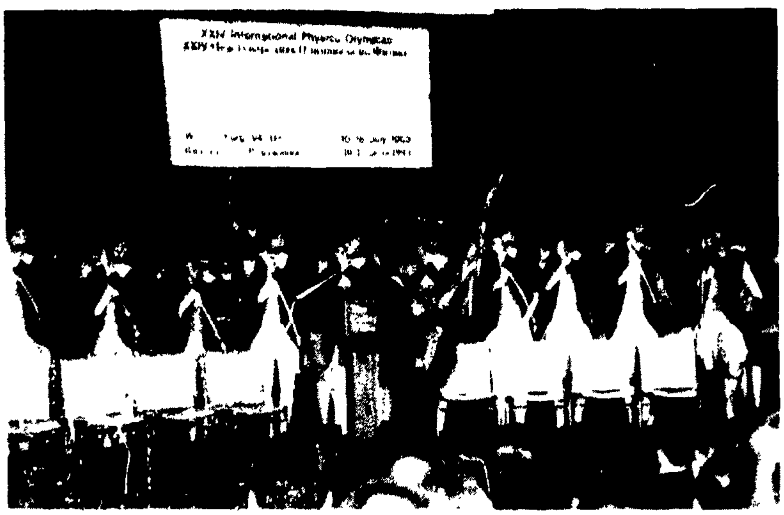
The Fife and Drum Corps of Williamsburg begin the Opening Ceremony

THE OPENING CEREMONY

INTERNATIONAL
PHYSICS OLYMPIAD
XXIV
WILLIAMSBURG
VIRGINIA • USA

Sunday, the eleventh of July,
Nineteen hundred and ninety-three
at 11 o'clock

Phi Beta Kappa Memorial Hall
The College of William and Mary
Williamsburg, Virginia
The United States of America



THE WHITE HOUSE

WASHINGTON

July 1, 1993

I am delighted to greet the participants of the 1993 International Physics Olympiad in Williamsburg, Virginia. This is the first time that the United States has hosted this event, and I am pleased that we have the opportunity to welcome the world's top physics students. I commend you for the accomplishments that have earned you this special honor and am confident that you will represent your countries with pride and distinction.

The study of physics is an admirable and worthwhile pursuit, yielding personal as well as academic fulfillment. It cultivates logical thinking skills, which you will find invaluable throughout your lives. Moreover, physics is an essential element in technological innovation. In conjunction with fields such as chemistry, engineering, and mathematics, it underlies scientific advances that help protect our environment, improve medical technology, and explore the outer reaches of space. As we enter the 21st century, the world will look to you to continue this legacy of innovation, design, and discovery.

Your superlative achievements in physics reflect a thirst for knowledge and understanding that will serve you well in your professional careers. I send you my best wishes for your future success.

Bill Clinton

XXIV International Physics Olympiad
10-18 July 1993
United States of America

Program Opening Ceremonies

PROCESSIONAL*

The Fifes and Drums of Colonial Williamsburg
Flag Bearers of The Participating Delegations

Australia	Austria
Belgium	Bulgaria
Canada	China
Colombia	Croatia
Cuba	Cyprus
Czech Republic	Estonia
Finland	Germany
Greece	Hungary
Iceland	Indonesia
Italy	Republic of Korea
Kuwait	Lithuania
Mexico	Netherlands
Norway	Poland
Romania	Russia
Singapore	Slovakia
Slovenia	Spain
Suriname	Sweden
Thailand	Turkey
Vietnam	Ukraine
United Kingdom	United States of America

*Please remain standing during the Processional

OPENING

National Anthem, The United States of America

The Fifes and Drums of Colonial Wlliamsburg

Welcoming Remarks

Arthur Eisenkraft
Executive Director, XXIV International Physics Olympiad

David Lutzer
Acting Provost, The College of William and Mary

Addresses

Leon Lederman
Chair, XXIV International Physics Olympiad

Eric Miller, 1992 Gold Medalist
XXIII International Physics Olympiad

Musical Interlude

The Fifes and Drums of Colonial Williamsburg

Comments

Reuben E. Al[illegible]
President, American Association of Physics Teachers

John Rigden
American Institute of Physics

Greetings

Gerhard Salinger
National Science Foundation

Closing Remarks

Judy R. Franz
Chair, *International Board*

Declaration of Opening

Recessional

The Fifes and Drums of Colonial Williamsburg

Reception by special invitation immediately after the Opening Ceremonies
Wren Building, The College of William and Mary

UNITED STATES DEPARTMENT OF EDUCATION

THE SECRETARY

TO THE PARTICIPANTS IN THE
24TH INTERNATIONAL PHYSICS OLYMPIAD
COLLEGE OF WILLIAM AND MARY
WILLIAMSBURG, VIRGINIA
JULY 10-18, 1993

It is a great privilege to send greetings and congratulations to the scholars, classroom teachers and sponsors who have carried out plans for such a distinguished group of physics students from all over the globe to participate in this 24th International Physics Olympiad competition

It is a distinct honor for the citizens of the United States to welcome you the top high school physics students from more than 40 countries I wish you well in the competition and hope you have an enjoyable stay in our nation. I also convey my congratulations to the United States planning committee serving as host to this international event

In May, I met with the 20 U S Physics Team finalists at the U S Department of Education in Washington to talk with them and to encourage each of them to continue their important journey in o the challenging field of science I encouraged them to combine the careers of education and science Many of those students indicated that they were inspired to continue in the field of physics by superior teachers, by their parents and mentors

To each distinguished student participant in the 24th International Physics Olympiad, I encourage you to continue the pursuit of academic excellence I urge you to consider combining the important careers of teaching, research and science. Educators in all parts of the world are looking to you to help achieve the education goals and reforms in education we are all pursuing as we move toward the 21st Century. I sincerely believe that all of you, as outstanding students participating in the Olympiad, will assist in meeting these challenges so that people everywhere can live in peace and greater harmony, respecting each other and assisting one another where there is need through science and education.

In the United States we believe, as you do in other countries, that the International Physics Olympiad competition furnishes the necessary opportunity for young high school students everywhere to receive world-wide recognition for outstanding intellectual achievements. Such recognition helps today's outstanding young students to receive a strong sense of who they are and an appreciation of our world and all who live in it. Such inspired action requires knowledge of many academic areas, of other cultures and appreciation for the aspirations of others

The U S Department of Education and the entire education community congratulate you for your academic stamina and for your commitment to education excellence.

You are all winners! Your participation in this competition will surely increase international understanding--a great opportunity for moving forward together through education

With highest regards and best wishes for continued success,

Yours sincerely,

Richard W. Riley

Richard W Riley

NATIONAL SCIENCE FOUNDATION
1800 G STREET, N.W.
WASHINGTON, D.C. 20550

OFFICE OF THE
DIRECTOR

TO THE PARTICIPANTS IN THE
XXIV INTERNATIONAL PHYSICS OLYMPIAD

WILLIAMSBURG, VA
July 11, 1993

I would like to extend my sincere congratulations to you, the contestants, on the accomplishments which have brought you here, as well as acknowledge the contributions of the parents and teachers who have encouraged you in your studies and preparations. You are all winners.

The National Science Foundation is proud to be the Principal Sponsor of the XXIV International Physics Olympiad. An Olympiad, in whatever field, demonstrates world class standards and excellence. Your achievements in physics make you role models for your peers and for younger students who follow. You demonstrate to everyone the caliber of our youth and the increasing ability of students in mastering advanced theoretical and experimental concepts.

The Olympiad also models the friendly competition that is the essence of how science is done. Each of you wants to do well - to be a Gold Medalist. At the same time, this is an opportunity to make friends with whom you will have professional contact throughout your life.

Science and technology together play critical roles in industrial competitiveness and in improving the standard of living; they form the basis for many of the important issues that face society today. The National Science Foundation, an agency of the Federal government, has responsibility for the health of science, mathematics, engineering, and technology in the United States. Those of you who maintain your interest in these fields and continue to pursue scientific and educational careers will undoubtedly come into contact with NSF in the future. We will be ready to assist you either through our education and human resource programs that span pre-school through post-graduate education and career development or through our support of basic and critical research.

We wish each of you success and fulfillment here and in your chosen careers.

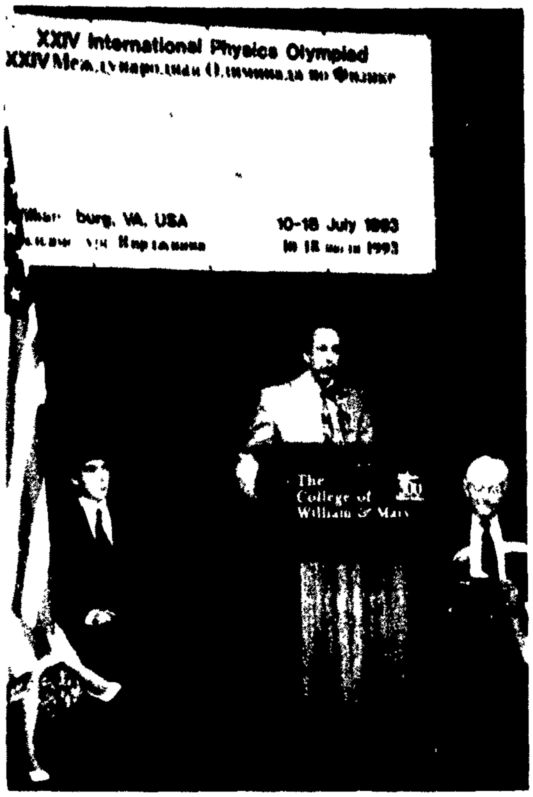
Frederick M. Bernthal
Deputy Director

Welcoming Remarks

Arthur Eisenkraft
Executive Director
XXIV International Physics Olympiad

We have gathered here to celebrate academic excellence. The 201 students representing 41 countries have studied and learned physics; they have honed their intellectual skills and can appreciate the world through the knowledge that is theirs. They can appreciate a rainbow, as everyone can, as an assortment of splendid colors. But their appreciation is not limited to their visual sense. They can perceive the more subtle beauty that comes when one understands the behavior of light, the shape of water droplets and the geometry of the world about us. We celebrate the knowledge that is theirs.

In the United States we are presently struggling with redefining our educational needs. We have committees and conferences that are trying to set standards for what students are capable of learning and what we should demand of them. The students with us today repesent the world class standard. They have learned far more than other students, far more than what was expected of them.



Arthur Eisenkraft welcomes the participants, as Eric Miller (l) and Leon Lederman (r) listen.

This week, these young prodigies will have a chance to demonstrate that their problem solving abilities surpass those of their peers anywhere in the world. Their arenas are two 3' by 5' tables. On one table are three theoretical problems with some paper and pens. Here the high school Olympians will individually search their minds for insights to problems that would challenge physics professors in

colleges or universities throughout the world. On the other table is experimental apparatus which must be delicately manipulated to eke out nature's subtle secrets.

Camaraderie is as important to science as competition. And at this year's Physics Olympiad, the students will begin relationships with some of their future colleagues in the world of science. When the students spin upside down at Busch Gardens, or tour the largest electron accelerator in the world, or view the wind tunnels at NASA or glimpse at American history through the lens of Colonial Williamsburg and the College of William & Mary, they will be forming bonds and friendships that will become the foundation of their future collaborations in science.

The participants of the XXIV International Physics Olympiad have brought pride to themselves, their families, their schools and teachers and to their countries. You are heroes of our world society. It is our honor that you have come to the USA to participate in our celebration. We hope that you may enjoy your stay with us.

Welcoming Remarks

David Lutzer,
Acting Provost
The College of William and Mary

Good morning, and welcome to Williamsburg and the College of William and Mary. It was three hundred years ago, in 1693, that England's King William and Queen Mary agreed to establish a college in Virginia, the second in North America. They named the school after themselves and ordered the new college to teach and study "the goode arts and sciences." For three centuries, we have taken that mission very seriously.

About 1760, William and Mary had a great professor and an even greater student. The professor was William Small, a professor of mathematics and natural sciences who came to the College after completing his studies at Scotland's University of Aberdeen. The student was Thomas Jefferson, whose two hundred and fiftieth birthday occurs this year. Small was Jefferson's mentor, introducing Jefferson to the ideas of the enlightenment and guiding his intellectual development. Jefferson later described Small as the man who "fixed the destinies of my life." It is in honor of Jefferson's great teacher that our Physics building is named.

Today we continue to emphasize "the good arts and sciences" even though we have added schools of Business, Education, Law, and Marine Science. We are very proud of our record in educating scientists. In the College's graduating class of 1993, for example, almost a third of the students majored in science or mathematics. For many years, a key feature of science education at William and Mary has been an emphasis on research by undergraduates. Like our colleagues around the nation, we have found that early exposure to science that is as close as possible to the frontiers is the best way to keep students interested in studying further science. Cirila Djordjevic, one of our Chemistry professors, summarized our view by saying: "You either teach the frontiers of science or the history of science. Take your choice."

In closing, let me add a special word of thanks to Professors von Baeyer and Champion of our physics department. It was their energy and dedication which brought the Physics Olympiad to William and Mary. It has been a monumental task and shows their commitment to educating students whom President Kennedy used to call "the best and the brightest." Finally, I wish good luck to each of the students in the Olympiad. Once again, welcome to Williamsburg and the College of William and Mary.

Opening Address

Leon Lederman
Chair, XXIV International Physics Olympiad

I'm here to welcome you — not only to the U.S., not only to Williamsburg, Va., but to the world community of physicists — those of you who stay in physics (some of you may drift into such lesser sciences as chemistry or biology — I forgive you) and become part of the 2600 year old family — a family that has had one goal: to know, to understand the inanimate world in which we live — how do galaxies form and the stars . . . what is their source of energy? Is there a beginning to the world and, if so, what came before? What is the composition of the dust from which we are all made? What is light and how do atoms work? Is there a fundamental simplicity to matter and energy and space and time? Can we understand complex systems which exhibit such curious properties as turbulence and superconductivity? Why are there only six quarks and six leptons and what is the origin of their masses?

The search for answers to these questions has been led by physicists starting in ancient Greece 2600 years ago . . . and it has changed the way humans live on this planet — it has created a vast increase in human capabilities and possibilities — but the technology based on physics has also created very serious problems for all inhabitants of our planet. Now whereas physics has provided a base of knowledge out of which technology emerged, it is not too useful to apportion blame and credit for the vast problems which technology has generated (as well as the vast benefits). It is more useful for some of us as physicists to think about how to solve the problems — or, since we are dealing with society, to help political leaders to solve these problems.

And we physicists have been part of an *international* war on ignorance long before there was a UN: just listen to the names of the people you will join when you say "I am a physicist!" Archimedes and Democritus, Ptolemy, Copernicus, Galileo, Kepler, Brahe, Zeeman, Yukawa, Newton, Fermi, Heisenberg, Bohr, Lorentz, Tomonaga, Faraday, Schrodinger, Einstein, Nishina, Thompson, Curie, de Broglie, Ampere, Coulomb, Lawrence, Feynman, Gell-Mann.

Physics began as an activity that did not pay attention to national boundaries: All of us from Norway to Suriname, from Novosibirsk to Argentina share a common experience of suffering to understand quantum mechanics and solve the Schrodinger equation for a periodic square well. This common heritage will serve us well as we increasingly collaborate in solving today's problems. Just look at the different nations collaborating at CERN, Fermilab and the astronomical observatories. We must continue to work together to

find a more environmentally benign source of inexpensive energy, to raise the standard of living of the underdeveloped countries or to work with geologists, oceanographers and atmospheric chemists to address the global problems of environment.

While all of us in physics are deeply impressed by our heritage of great scientists of the past, I have to tell you how moved I was a bit earlier when I watched the students, placing their flags on the stage. As each of you walked up, so young, intent, with the enthusiasm and intelligence shining out of your eyes, I realized that we also have a heritage of great scientists of the future. As long as we can continue to collect a group of incredible students like this, physics will remain the leading science it has always been.

One more assurance to you — physics will still have problems to solve long after your children are grown up — problems that range from quantum cosmology to chaos and materials science, and physics will continue to be a welcome and essential tool in advancing all other disciplines — chemistry, biology and neurophysiology — because we understand computers, because we can bring in exotic mathematical techniques and because our instruments — counters and accelerators and light sources and wire chambers — are essential for other fields from archeology to zoology to molecular medicine.

I would like to close with a story that is meant mostly for the American students. There was a very hungry mouse, hiding in his hole in the kitchen. The mouse knew exactly where the cheese was but he was afraid of the cat whom he heard pacing back and forth outside his hole. Suddenly he heard a bark —"Oh, that's not the cat, it's the old dog — I can run faster than him," said the mouse who then dashed out of his hole. The cat pounced on him and gobbled him up — As he licked his whiskers, the cat said: "It's always good to know (*at least*) two languages."

So, welcome to the Olympiad and may you all win gold medals!

Opening Address

Eric D. Miller, *Gold Medalist (USA)*
XXIII International Physics Olympiad, Espoo, Finland 1992

Good morning. It is a pleasure to welcome you to the United States, and to the twenty-fourth International Physics Olympiad.

I hope that you are all very excited to be here, as I was a year ago in Helsinki, Finland. I imagine that many of you are also very nervous. I remember questioning whether I really deserved to be one of the five people selected to represent my country, whether I knew as much physics as I would need to know, and whether I should be spending all of my time studying rather than meeting people and seeing the local sights. But by the end of the Olympiad, my nervousness and doubts had dissipated, and I had found time both to study and to enjoy the experience of being in a foreign country.

I hope that you will do the same, and I hope that you do not focus too narrowly on the competition. You should all be commended for the efforts that you have made just to get here, and you are to be congratulated for your achievement. Hopefully, some of you will leave here excited about studying physics, and you will go on to a productive career in that field, having derived a great benefit from your experience here. But I believe that even those of you who do not remain in physics will derive no less benefit from your experiences here than will your colleagues who do, for what you have learned in studying physics, and, more importantly, what you have learned of the enterprise of studying physics, will be important to you throughout your life.

Your study of physics will make you better judges of important issues facing society as a whole. If they ever existed, the days when the scientific community could operate in a vacuum, immune from social pressures and influences, are now gone. In this country, for example, there has recently been a debate over the future of the superconducting supercollider, an 87 kilometer proton accelerator to be built near Dallas, Texas. Public officials have questioned whether the scientific knowledge to gained from the collider justifies its enormous cost. Whatever one may think of the merits of the project, it cannot be denied that only a scientifically knowledgeable public can make intelligent decisions about whether to fund scientific research, and how to apply its results.

The primary cause of human misery in the world today is not a lack of scientific knowledge, or even a lack of technological tools to meet important social needs. Rather, it is the misguided misapplication of this knowledge and these tools. The world needs more informed non-scientists who can evaluate the merits of proposed scientific projects, and who can judge the difficult

ethical questions that will surely arise from new discoveries. We would do well to remember Einstein's observation that "Science can only ascertain what is, not what should be, and outside of its domain value judgments of all kinds remain necessary."

While what you have learned of physics will doubtless prove important to you in the future, I believe that what you have learned of the process of learning physics will prove even more important. What exactly is "the process of learning physics"? The Olympiad offers us an artificial example, for here, everyone knows for sure that there is a right answer to every problem. By the time you leave her, everyone will know with certainty what that right answer is, and you will know whether or not you have found the answer.

But the study of physics should teach us that such convictions of certainty are hopeless delusions. Scientific progress in the Middle Ages was impeded by people who clung to incorrect beliefs about the way the world worked. Today we have a tendency to ridicule those who subscribed to Aristotelian theories of physics, but the relevant point is not that the theories were wrong, though they were, not that those who believed in them were stupid, because they were not. Rather, the problem was an unwillingness to question these ideas, to subject them to experimental scrutiny.

Today, of course, we recognize that physics advances through the falsification of hypotheses. This is a fact not always appreciated by the general public, who seem to expect scientists to "prove" things. But science is, fundamentally, a method for disproving things. The theories on the basis of which you will solve problems here would quickly be changed if contrary evidence were found. The history of progress in physics should teach us to ask not for proof, but for evidence, and it should remind us of the importance of questioning our beliefs, and of actively seeking evidence that might show us to be mistaken. Above all, the study of physics should remind us of the observation of Oliver Wendell Holmes, one of America's greates jurists, who noted that "Certitude is not the test of certainty."

The intellectual humility, and the spirit of careful inquiry, to be gained from physics will serve you well in all aspects of life. To choose just one example, history shows us the importance of questioning those in authority, of carefully examining the assumptions underlying their policies. A skeptical, questioning populace is the best defense of liberty; a credulous populace is the surest invitation to despotism.

And so, regardless of whether you win a medal here, regardless of whether you become a physicist, what you learn during the days ahead, and what you have already learned in your study of physics, will guide you for the rest of your life. Again, I want to congratulate you for everything that you have already achieved, and I wish you all the best of luck in the competition ahead Enjoy the Olympiad!

Thank you

SOCIAL, CULTURAL AND SCIENTIFIC EVENTS

PROGRAM FOR THE STUDENTS

SUNDAY, JULY 11

7:30-10:30 AM	Breakfast (Commons)
9:00 AM	Rehearsal for Opening Ceremony (one student from each country) (Phi Beta Kappa Hall)
11:00 AM-12:00 PM	Opening Ceremony (Phi Beta Kappa Hall)
12:30-1:30 PM	Lunch (Market Place)
2:00-5:30 PM	Tour of Colonial Williamsburg
6:00 PM	Dinner (Market Place)

MONDAY, JULY 12

6:30-7:30 AM	Breakfast (Commons)
8:00 AM -1:00 PM	Theoretical Exam (Wm & Mary Hall) Snack & Lunch during exam
2:00-5:00 PM	Water Country USA
5:30-7:30 PM	Barbecue Dinner (with Leaders) Hosted by Merck Institute (In front of Commons)
8:00-10:00 PM	Demonstration Shows (William Small and Andrews)

TUESDAY, JULY 13 *A Day at Busch Gardens*

6:30-7:30 AM	Breakfast (Commons)
7:15 AM	Bus pick-up at Commons Depart for Busch Gardens (Picnic Lunch at Busch: Black Forest Picnic Area)
5:00 PM	Depart for Campus
6:00-7:00 PM	Dinner (Market Place)

WEDNESDAY, JULY 14

6:30-7:30 AM	Breakfast (Commons)
8:00 AM-1:00 PM	Experimental Exam - *GROUP 1* (Wm & Mary Hall) Snack & Lunch during exam

1:45 PM	*GROUP 1* Depart from Wm & Mary Hall
1:45-6:00 PM	Excursion to CEBAF - *GROUP 1*
8:30 AM-1:00 PM	Trip to NASA - *GROUP 2*
12:30 PM	*GROUP 2* Bus for Return to campus
2:00-7:00 PM	Experimental Exam - *GROUP 2* (Wm & Mary Hall) Snack during exam
6:00-10:00 PM	Dinner and fun (with Leaders) (Paul's Deli/College Delly)

THURSDAY, JULY 15 *IBM AND EDUQUEST "COMPUTER WORKSHOPS"*

7:30-8:30 AM	Breakfast (Commons)
8:30-10:00 AM	Computer Workshop - *GROUP 1A*
10:30 AM-12:00 PM	Free Time - *GROUP 1A*
8:30-10:00 AM	Free Time - *GROUP 1B*
10:30 AM-12:00 PM	Computer Workshop - *GROUP 1B*
12:00 PM	Lunch (Market Place) - *GROUP 1*
1:30 PM	*GROUP 1* - Depart from Commons
1:30-5:30 PM	Excursion to NASA - *GROUP 1*
8:40 AM	*GROUP 2* - Depart from Commons
8:40 AM- 1:30 PM	Excursion and lunch at CEBAF - *GROUP 2*
2:00-3:30 PM	Computer Workshop - *GROUP 2A*
4:00-5:30 PM	Free Time - *GROUP 2A*
2:00-3:30 PM	Free Time - *GROUP 2B*
4:00-5:30 PM	Computer Workshop - *GROUP 2B*
6:00 PM	Dinner (Market Place)
7:00 PM	Paper Olympics (Wm Small & Andrews)

FRIDAY, JULY 16 *DURACELL "DAY AT THE BEACH"*

7:30-8:30 AM	Breakfast (Commons)
8:30 AM	Depart from Commons
8:30 AM - 5:00 PM	Duracell Presents: "A Day at the Beach"
6:00-7:30 PM	Dinner Party (Market Place)
7:30-10:00 PM	American Music Fest (with Leaders)

SATURDAY, JULY 17

7:30-8:30 AM	Breakfast (Commons)
9:00 AM-12:00 PM	Free Time
12:00-1:00 PM	Lunch (Market Place)
2:00 PM	Closing Ceremony (Phi Beta Kappa Hall)
3:30 PM	Reception (Andrews Foyer)
6:00 PM	Banquet (Trinkle Hall)

SUNDAY, JULY 18

6:30-7:30 AM	Breakfast(Commons)
	Tours of Washington, DC
	Depart for Airports

Students learn about electronics at CEBAF

PROGRAM FOR LEADERS

SUNDAY, JULY 11

7:30-9:00 AM	Breakfast (Hospitality House [HH]) Introduction to computers
11:00 AM	Opening Ceremony (Phi Beta Kappa Hall) - campus)
12:00 PM	Reception (Wren Building - campus)
1:30-2:30 PM	Lunch (Hospitality House)
2:30 PM	Discussion of Theoretical Exam Empire Ballroom, 2nd Floor (Hospitality House)
7:30-8:30 PM	Buffet Dinner (Hospitality House)
8:30 PM -	Continue Work on Exam (printing, translations, etc.)

MONDAY, JULY 12

7:30-9:00 AM	Breakfast (Hospitality House)
9:00-12:00 PM	Tour of Colonial Williamsburg
1:00-2:00 PM	Lunch (Hospitality House)
3:00-5:00 PM	Water Country USA Excursion (Buses depart HH at 3 PM)
5:30-7:30 PM	Barbecue Dinner (with students) (Front of Commons - campus)
8:00-10:00 PM	Demonstration Shows (William Small Physical Laboratory - campus)

TUESDAY, JULY 13

6:30-7:30 AM	Breakfast (Hospitality House)
7:45 AM	Buses depart for Busch Gardens
8:00 12:00 PM	Busch Gardens
12:00 PM	Picnic Lunch (Busch Gardens)
1:00 PM	Return by bus to HH
2:00 PM	Discussion of Experimental Exam Empire Ballroom, 2nd Floor (Hospitality House)

7:30-8:30 PM	Buffet Dinner (Hospitality House)
8:30 PM	Continue Work on Exams Printing, Translations, etc.

WEDNESDAY, JULY 14

7:30-8:30 AM	Breakfast (Hospitality House)
9:00 AM -1:00 PM	Trip to CEBAF (Continuous Electron Beam Accelerator Facility) (Buses depart from HH at 9 AM)
12:00 PM	Lunch at CEBAF
2:00-7:00 PM	Tour of NASA
7:00-9:00 PM	Dinner (with students) Paul's & College Delis
After 9:00 PM	Theoretical Exams are returned (Huntington Room - HH)

THURSDAY, JULY 15

7:30-9:00 AM	Breakfast (Hospitality House)
9:00 AM-5:00 PM	Grade Discussions by schedule
12:00 PM	Lunch (City of Colonial Williamsburg)
6:00 PM	Dinner (with local families in their homes) Meet in lobby of HH at 6 PM
After 10:00 PM	Return of Experimental exams (Huntington Room - HH)

FRIDAY, JULY 16

7:30-9:00 AM	Breakfast (Hospitality House)
8:00 AM-3:30 PM	Experimental Grade Discussions by schedule
8:00-9:30 AM	Computer Workshop I
10:00-11:30 AM	Computer Workshop II
12:00-1:00 PM	Lunch (City of Colonial Williamsburg)
4:00-6:00 PM	Board Meeting Empire A&B (Hospitality House)
6:00-7:30 PM	Dinner Party (with students) (Market Place - campus)
7:30-10:00 PM	American Music Fest

SATURDAY, JULY 17

7:30-9:00 AM	Breakfast (Hospitality House)
9:00 AM-12:00 PM	Free Time
12:00-1:00 PM	Lunch (Hospitality House)
2:00 PM	Closing Ceremony (Phi Beta Kappa Hall)
3:30 PM	Reception (Andrews Foyer)
6:00 PM	Banquet (Trinkle Hall)

SUNDAY, JULY 18

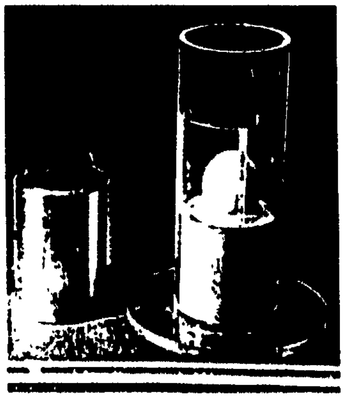
6:30-7:30	Breakfast (Hospitality House) Tours of Washington, DC Depart for Airports

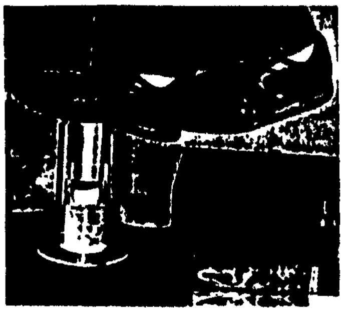
Events of the XXIV International Physics Olympiad

Social	Cultural	Scientific
Water Country, USA	Colonial Williamsburg	Demonstration Show, Physics IQ test, Strobe Photography
Busch Gardens Amusement Park	College of William & Mary (300th Anniversary)	Physics of Roller Coasters at Busch Gardens
Deli nights - Karioke and Board Games	Visit to shopping mall	Continous Electron Beam Accelerator Facility (CEBAF)
Paper Olympics	American Music Fest	NASA Langeley
Virginia Beach	Tour of Washington DC (for teams with afternoon or evening departure times)	Paper Olympics
Banquet	Visit to American Homes (leaders only)	Computer workshop
	American Barbecue dinner	

PROPERTIES OF MATERIALS **M-837**

Compressive Stress **Stand on Egg**



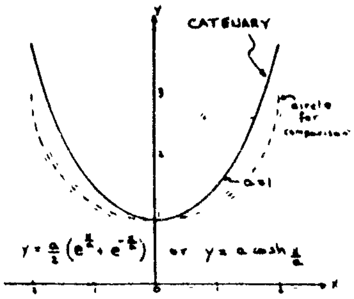


DEMONSTRATION
Seat egg with large end down in sand about 10-15 mm. Carefully align axis of egg to be vertical and centered on piston. Arrange block or short stool so demonstrator can step from stool to top of piston easily and SLOWLY. Most eggs are always safe at 80#, usually safe at 120#, sometimes at 150# and rarely ever at 180#.

CONSTRUCT using acrylic tubing about 8 cm dia into which a side hole has been milled to accept egg. Cement tubing to square or circular acrylic base with ethylene dichloride or other bonding agent for acrylics. Turn Al cylinder ~10-12 cm long to slide loosely in tubing. Cement sponge rubber 2-3 cm thick on one end of Al cylinder as cushion.

DISCUSS properties of catenary and hold hanging chain to show approx. shape to egg. Compare Roman arches to Greek columns for span and strength. Eskimo igloos and McDonald's arches are shaped as inverted catenaries approximately.

SUGGEST students try to squeeze egg placed with long axis between knees. TRY OUTSIDE WITH OLD CLOTHES.



RELATED REFERENCES
TPT 30, 42 (1992) - "Undergraduate Investigation of Nitinol" - Memory shape alloy o Ni/Ti, deformed to new shape at low T, recovers original shape when heated. Example of how to interest students in properties of materials.

• • ***S A F E T Y N O T E*** • •
When demonstrator stands on egg, have assistant stand beside steadying one arm in case egg breaks suddenly.

Ease of Setup/Construction: B/C

One of the many demonstrations from Minnix & Carpenter

PAPER TOWER

TEAM # ________ PLACE ________

POINTS ________

FINAL TOWER HEIGHT ________ CERTIFIED BY ________________
(official judge)

OBJECTIVE:
To construct a free-standing tower of maximum height using a single sheet of paper.

APPARATUS:
1. Each team will be supplied with one sheet of colored duplicator paper (21.6 x 27.9 cm) and one strip of clear cellophane tape (30 cm long) on arrival at the test site.
2. The paper may not be soaked, painted, or otherwise chemically treated to add rigidity. No other glues or tapes may be used.
3. Construction aids such as meter sticks, scissors, and straight edges will be available.

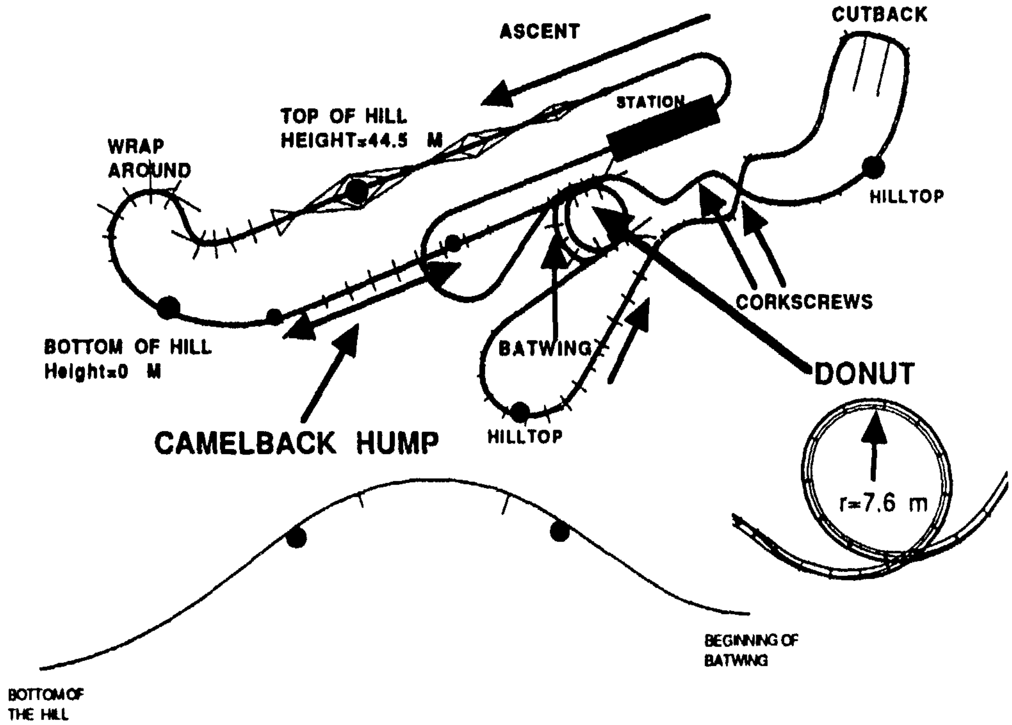
COMPETITION:
1. Each team may have only one entry.
2. The sheet of paper may be cut into pieces and reassembled as desired. Parts may be rolled, folded, or slit.
3. Tape is to be used to fasten parts of the tower together. The tape may NOT be used to attach the tower to the floor or any other object.
4. A tower shall be declared free-standing, if it remains self-supporting for more than 10 seconds.
5. Height is determined by measuring the perpendicular distance from the highest point of the tower to the floor.
6. Each team must complete the construction of its tower within 20 minutes.
7. The height may be measured two times during that time period, as a team requests.

SCORING:
The tallest tower will receive first place, etc.

Height of tower ________ (cm)

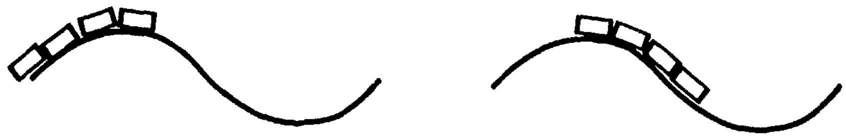
One of the tasks at the paper Olympics

DRACHEN FIRE



T 1. Sometimes the free fall motion of the rider differs from the motion of a coaster car, because the car is part of an extended body, while the person is like a point. Riding in the front car is much different from riding in the last car. The first car and last car will have different velocity, acceleration, normal force and sensations at the top and bottom of the hills. Indicate these differences by diagram or words.

Top of Hill (first car) | Top of Hill (last car)



Bottom of Hill (first car)

Bottom of Hill (last car)

2 Ride the coaster close to the front and then close to the back. Do your experiences compare to the theory? Where on the ride is the difference between front and last cars the greatest?

3 Note the parabolic shape of the Camelback Hump.

a. Design safe activities using found items or your body to investigate the near weightlessness experienced on the Camelback Hump. Test them and describe your experiences. In which car is the "weightlessness" the best?

CLOSING CEREMONIES XXIV INTERNATIONAL PHYSICS OLYMPIAD

Phi Beta Kappa Memorial Hall
The College of William and Mary
Williamsburg, Virginia
The United States of America

Saturday, the seventeenth of July,
Nineteen hundred and ninety-three
at two o'clock

The XXIV International Physics Olympiad
was organized by the
American Association of Physics Teachers
with the assistance of the
American Institute of Physics.

XXIV International Physics Olympiad
10-18 July 1993
United States of America

Closing Ceremonies

The Prelude

Serenade	*F. J. Haydn*
Fantasie in A Minor	*G. P. Telemann*
Suite of Renaissance Dances	*L. von Beethoven*
Sonatina	*L. von Beethoven*

Flute: Susan Key Guitar: Michael Pratt

Opening Remarks

Arthur Eisenkraft
Executive Director, XXIV International Physics Olympiad

National Anthem

The Star-Spangled Banner — *Francis Scott Key*
Rebecca Paige Mayer

Addresses

Frank Gibbard
Vice President Research and Development, Duracell International

James J. Wynne
IBM Corporation

Bernard V. Khoury
Executive Officer, American Association of Physics Teachers

The Awards Ceremony

Val L. Fitch, *Nobel Laureate, 1980*

Jerome I. Friedman, *Nobel Laureate, 1990*

Leon M. Lederman, *Nobel Laureate, 1988*
Chair, XXIV International Physics Olympiad

Hans von Baeyer
Chair, Host Committee, XXIV International Physics Olympiad

SPECIAL AWARDS

PRESENTATION OF HONORABLE MENTIONS

THE INTERLUDE

Andante — *J. S. Bach*

PRESENTATION OF BRONZE MEDALS

PRESENTATION OF SILVER MEDALS

PRESENTATION OF GOLD MEDALS

THE EXCHANGE

Simple Gifts from Appalachian Spring — *Aaron Copeland*
The Big Sea, My Native Land — *Wang Li Peng*

REMARKS

Anthony P. French
Chair, Academic Committee, XXIV International Physics Olympiad

Shen Keqi
XXV International Physics Olympiad, The People's Republic of China

CLOSING REMARKS

THE CLOSING FANFARE:

Rondo in D Major — *W. A. Mozart*

You are cordially invited to honor all of the paricipants
immediately following the Closing Ceremonies
Foyer, Andrews Hall
The College of William and Mary

PARTICIPATING NOBEL LAUREATES

Val L. Fitch was born in Nebraska in 1923. He obtained a B.E. degree at McGill University (Canada) in 1948 and a Ph.D. at Columbia University in 1954. He then went to Princeton University where he is now James S. McDonnell Distinguished University Professor. In 1964, with James W. Cronin, he performed a fundamental experiment that demonstrated a subtle and unexpected breakdown of time-reversal invariance, evidenced by the decay of neutral K-mesons into pairs of pions. For this work, Fitch and Cronin were awarded the Nobel Prize in Physics in 1980.

Jerome I. Friedman was born in Chicago in 1930. He studied at the University of Chicago, where he received the A B. degree in 1950, the M.S. in 1953, and the Ph.D. in 1956. After a short period as a Research Associate at Stanford University, he joined the faculty of the Massachusetts Institute of Technology, where he has been ever since. In 1968, together with Henry W. Kendall of MIT and Richard E. Taylor of Stanford University, he carried out experiments on the nuclear scattering of high-energy electrons (from the Stanford Linear Accelerator) that gave the first direct evidence for the existence of point-like particles (later to be called quarks) within the proton and the neutron. For this work, Friedman, Kendall, and Taylor were awarded the Nobel Prize in 1990.

Leon M. Lederman was born in New York City in 1922. He obtained his B.S. degree at the City College of New York in 1943, followed by the A.M. (1948) and the Ph.D. (1951) at Columbia University. From 1952 to 1989 he was on the faculty of Columbia University, but he also served as Director of the world-famous Fermilab (Batavia, Illinois) from 1979 to 1989. In that capacity he mobilized the resources of the Laboratory in support of science education projects. He was Frank L. Sulzberger Professor of Physics at the University of Chicago and currently is the Pritzker Professor of Science at Illinois Institute of Technology. In 1960-62, working with Melvin Schwartz and Jack Steinberger, he constructed a special nuclear detector, designed to detect neutrino-induced reactions, and used it to demonstrate the existence of a new type of neutrino — the muon neutrino — emitted in the decay of pions and distinct from the familiar electron neutrino of radioactive beta-decay. For this work, Lederman, Schwartz, and Steinberger were awarded the Nobel Prize in 1988.

privileged people got to hear my only public performance of Twist and Shout, and an American party with Bluegrass and Jazz performances.

The individuals who contributed to this effort are listed in your program. I am beholden to all of them for their dedication to the task at hand. A week of this intensity bonds people for life and all of the people who kept us afloat this week have created a special place in my heart. And if your life as a participant or leader has been enriched even a fraction that mine has, you are a very fortunate person. But if I continue to dwell on this, I will become improperly emotional for this very happy occasion.

In closing, let me tell you about my Olympiad hope for the world and America. One day, schoolchildren will look at you here today, and see you as the heroes that you are. And they will recognize that with hard work and dedication, they can achieve what you have achieved and dream that one day they may represent their country in an academic event.

ADDRESS

FRANK GIBBARD
VICE PRESIDENT RESEARCH AND DEVELOPMENT
DURACELL INTERNATIONAL

Good Afternoon.

I am very pleased to be here in the midst of so many physicists. Having been educated as a physical chemist, I have always felt a special affinity for your subject.

Not long ago I was discussing alternative careers in science with a colleague, and the subject of physics came up. My colleague said, "I have always appreciated the intelligence and mathematical ability of physicists, and many of them are fine fellows; but would you want your daughter to marry one?" My reply effectively cut off this line of conversation. I said, "My daughter is a physicist!"

Well, to the point of my talk, I bring you greetings on behalf of the 8,000 Duracell employees worldwide, and especially from the nearly 300 scientists, engineers and technicians at the Duracell Worldwide Technology Center in Needham, Massachusetts. The role of the Technology Center within Duracell is twofold:

> First, we help to ensure that the existing Duracell products sold throughout the world are premium products of the highest quality.
>
> Second, we invent and develop new battery technology which will generate new products for Duracell.

As Vice President of Research, Development and Advanced Engineering, my job is to administer the Technology Center. Because of my position in Duracell, I have recently become acutely aware of three trends in our growing company.

> The first trend is the increasingly *global nature* of our business, in which about half our sales come from outside the United States.
>
> The second is the increasing requirements for physical science, engineering, and mathematics in the design of new battery products.
>
> The third is our continuing need for a supply of highly-educated scientists, as our Technology Center has grown by 60 percent during the past two years.

It is not hard to see why these three forces: *Globalization, Increased Technical Requirements and the Need to Add Staff*, have impelled Duracell, and similar growing companies, to invest TODAY in the scientists of TOMORROW.

That is why we are a major sup‚ ᐨter of the International Physics Olympiad. You know, a country tends to *produce* that which it *values* and *recognizes*. When most of the industrialized countries of the world recognize and reward rock music stars and professional athletes, we create the desire in our young people to imitate these "role models." The Physics Olympiad provides an international forum for recogn˙˙on of the excellence in physical science, which Duracell and the other ›ponsors want to nurture and encourage.

You young scientists are the models which we want to hold up to the world as worthy of imitation!

Support of education in science is not new for Duracell. For 11 years Duracell has sponsored the National Science Teachers Scholarship, which has awarded more than $500,000 in cash and scholarships to students aspiring to careers in science. I would be remiss if I did not mention that Arthur Eisenkraft, Executive Director of the XXIV Physics Olympiad, has served for years as the head judge of the Duracell/National Science Teachers Scholarship competition.

Our Technology Center in Massachusetts is also participating in a very direct way in science education of young people. When an American Chemical Society study showed that children in the U.S. begin to lose interest in science by the fourth grade of elementary school, more than 40 of our scientists volunteered to go into the elementary schools to present hands-on experiments in support of the teachers.

As I said earlier, one of the main purposes of the Olympiad is recognition, and at this time I want to recognize all who competed, and especially those who won medals in recognition of your superior accomplishments. I am sure that each of you will look back on your participation in the International Physics Olympiad with a feeling of achievement and pride.

In conclusion, let me express the thanks of Duracell and the other sponsors to the organizing committee and to Dr. Arthur Eisenkraft for *their* accomplishment in the difficult task of coordinating the International Physics Olympiad.

Good luck, and best wishes as you return to your homes, wherever in the world they may be.

Speech

James J. Wynne
IBM Corporation
American Physical Society
Optical Society of America

It is my pleasure to be here to participate in this wonderful international event, which brings together academically excellent high school students from around the world, together with their academic leaders. I stand here as the representative of several prominent international organizations, all of which recognize the vital importance of scientific and technical literacy for all of our citizens. My role has been to help marshal the resources of these organizations to enhance science education, and, in particular, physics education, for the enhancement of the quality of life in all of our countries.

We need technically literate citizens to understand important matters that affect all of us, from the latest developments in medical science to the causes and remedies for environmental pollution to the technology of the information revolution. From this pool of technically literate citizens will come the technical workers of the future and the leaders who will discover new scientific principles and develop new technology. I expect that many of you will take on that mantle of leadership in the not-to-distant future.

This event epitomizes the best of the best in physics education. The students have earned their way onto their national teams by participating in rigorous competitions. Here, these students meet and compete with counterparts from other countries. Through this event, you get to test yourselves and stretch your minds to the utmost of your abilities. Furthermore, the friendships you develop with the other students lead to an understanding of our different cultures, which will serve to promote good relationships between our respective countries in the future. I applaud all of you for a job well done.

Let me close by giving special recognition to the academic leaders. You have been tireless in giving your time and energy in the service of your chosen profession, the teaching of physics. You all show the admirable qualities that I, myself, was fortunate to enjoy 33 years ago in the person of my own high school physics teacher, Lewis Love of Great Neck, NY. He continues to be an enthusiastic and inspiring teacher. Those of us lucky enough to have such teachers should always remember to pay homage to those outstanding members of that most noble of all professions, the profession of teaching.

CLOSING REMARKS

LEON LEDERMAN
CHAIR, XXIV INTERNATIONAL PHYSICS OLYMPIAD

In a few days, this group of young people will spread out to the four corners of the world — each of you have represented your countries well. I hope many of you have made new friends, have exchanged e-mail addresses and will bring home, in addition to the medals and T-shirts and other experiences, a sense of *belonging* to a *world-wide community* — the community of *science* and, for many of you, the smaller community of physicists.

Physicists have no secret handshake — perhaps we should have one so that we can recognize one another if we meet in strange cities someday. If there were to be an identification, I would suggest a small button with the number "137." This is the reciprocal of $e^2/\hbar c$ and it is a dimensionless number — perhaps the most important pure number in physics.

It may be useful for me to comment generally on the field of physics. Almost in any direction we find activities of intense interest from the abstract fields of astrophysics and particle physics to materials sciences to atomic, molecular and optical physics to nuclear physics as well as the hyphenated fields of chemical physics, bio-physics and the renewed interest in fundamental questions of quantum mechanics.

Now you have, in this week, experienced what is characteristic of science: the exquisite mixture of collaboration and competition. This is most appropriately illustrated by the relation of Niels Bohr, who was a founder of quantum mechanics, and Albert Einstein — who could not accept the basic premises. They argued about it continually — even passionately — yet they also loved one another. One day, they went for a walk in the woods, arguing, of course, when they came face-to-face with a huge bear. "Run", said Einstein, "It's a bear!" Bohr disagreed, "Albert, you know you cannot outrun a bear." "I don't have to outrun the bear, I have only to outrun you", Einstein pointed out.

Let me tell you prospective scientists and even prospective physicists one of the major problems we all share — our teachers like Bohr, Rutherford, Heisenberg, Schrodinger, Fermi, Landau, Kapitza and our students' students, you Olympians, with or without your medal; that is the difficulty of transmitting our excitement and our passion to the non-scientists — even the difficulty of transmitting to colleagues in other fields of science. How do I tell my father-in-law or my medical doctor about the importance of the two-neutrino research that gave me my Nobel Prize? Or the work of Val Fitch here who discovered the breakdown of C-P symmetry in elementary particle decays, or

Jerome Friedman whose scattering experiments provided evidence of the reality of quarks?

Just the lack of TV and journalists here today is proof of the problem. And yet, without the knowledge represented by the three of us — we could not possibly understand what mankind has been seeking for 2500 years: an understanding of the ultimate nature of substance. But what we did is no more abstract now than were Maxwell's equations in 1880. How do we respond when the politician or the intelligent citizen says, "Who cares if there are two neutrinos — or if anti-matter and matter are not totally symmetric or if quarks exist."

The true value of scientific knowledge is concealed in its future. But, ultimately it is a problem of teaching, and what is the most important advice we can give to you? As you learn, you must teach. You must consider teaching as one of the most solemn of your obligations as a physicist. You must teach those younger than you, your family, your friends, citizens of your community. Someone estimated that if every physicist in the world could reach a few hundred people — transmit the depth and the power of fundamental science, try to convey that feeling of excitement and beauty that converted you to devote your life to science — that is a crucial role all of us must accept. In the ups and downs of the scientific enterprise over the past few hundred years, we have never had a period where the human race is more in need of a robust international scientific community and, at the same time, the dark forces of irrational, anti-science, superstitious, fundamentalists have never been more threatening.

Well, to illustrate the problem, I'll conclude with a story that shows the diversity of scientific talent: the famous proof that all odd numbers are prime. (For this story we'll assume that "one" qualifies as a prime number).

> The mathematician says, "1 is a prime, 3 is a prime, 5 is a prime, 7 is a prime, by induction, all odd numbers are prime."
>
> The chemist says, "1 is a prime, 3 is a prime, 5 is a prime, 7 is a prime, 9 is a prime . . ." Chemists just don't know what a prime number is.
>
> The physicist says, "1 is a prime, 3 is a prime, 5 is a prime, 7 is a prime, 9 is an experimental error . . ."
>
> And the computer scientist says, "1 is a prime, 3 is a prime, 5 is a prime, 7 is a prime, 7 is a prime, 7 is a prime . . ."

So that's my advice. Bon voyage!

Award Winners

GOLD MEDALISTS

Junan Zhang	China	40.65
Harald Pfeiffer	Germany	40.65
Linbo Li	China	40.3
Sándor Katz	Hungary	39.8
Calin Ciocirlie	Romania	38.15
Tomá Kocka	Czech Republic	38.05
Roman Belenov	Russia	37.85
Iosif Bena	Romania	36.65
Vassili Larkin	Russia	36.6
Antonin Machacek	Great Britain	36.5
Gábor Veres	Hungary	36.45
Salih Adem	Turkey	36.4
Dean Jens	U.S.A.	36.4
Martin Benes	Czech Republic	36.25
Lajos Molnár	Hungary	36.25
Stepan Andreenko	Russia	36.25
Renat Jakupov	Ukraine	36.25
Alireza Shahidzadeh*	Iran	36.25

SILVER MEDALISTS

Martin Kassabov	Bulgaria	35.6
Zhanfeng Jia	China	35.55
Yongjik Kim	Korea	35.55
Denis Chigirev	Russia	35.25
Thomas Dent	Great Britain	34.25
Anatoli Olkhovets	Ukraine	34
Carsten Geckeler	Germany	33.8
Milos Gaj	Slovenia	33.5
Oleg Shpirko	Ukraine	32.95
Christian Fleischhack	Germany	32.85
Jirí Vanícek	Czechoslovakia	32
Jaromir Fiurasek	Czech Republic	32
Tao Wei	China	31.75
Robin Morris	Great Britain	31.6
Daniel Schepler	U.S.A.	31.55
Denis Kislovsky	Russia	31

BRONZE MEDALISTS

Egidijus Anisimovas	Lithuania	30.8
Reimar Finken	Germany	30.5
Akshay Venkatesh	Australia	30.45
Emanuel Tutuc	Romania	29.25
Oki Gunawan	Indonesia	29.05
Gregor Veble	Slovenia	29
Ilia Vassilev	Bulgaria	28.55
Milos Volauf	Slovakia	28.5
Yahyanejad Mehdi*	Iran	28.33
James Anderson	Great Britain	28.3
Péter Urbán	Hungary	28
Andrei Alexandru	Romania	28
Sinan Arslan	Turkey	28
Erwin Portuondo Campa	Cuba	27.75
Chee We Ng	Singapore	27.7
Hal J. Burch	U.S.A.	27.7
Zhining Huang	China	27.6
Marco Galimberti	Italy	27.43
Ioannis Vetsikas	Greece	27.35
Bojan Gornik	Slovenia	27.33
Yoo Chul Chung	Korea	27.25
Andras Major	Germany	27.05
Robert Kry	Canada	27
Erik Larsson	Sweden	27
IacopoCarusotto	Italy	26.7
Xiao Dong Yang	Canada	26.65
Jurgen Hissen	Canada	26.6
Frank Van Lankvelt	Netherlands	26.5
Thanh Minh Thái	Vietnam	26.5
Dmitri Linde	U.S.A.	26.3
Alexey Kvitsinski	Ukraine	26.15
Yongil Shin	Korea	26.05
Jan-Alexander Heimel	Netherlands	26

HONORABLE MENTION

David Weickhardt	Australia	25.75
Adrian Muresan	Romania	25.45
Safarian Saviz*	Iran	25.42
Simon Burton	Australia	24.75
Ivan Daikov	Bulgaria	24.5
Paul Mitchener	Great Britain	24.5

Kamil Budinsky	Slovakia	24
Chang Shih Chan	U.S.A.	23.8
Seref Burak Özaydemir	Turkey	23.75
Mariusz Szyposzynski	Poland	23.55
Anton Darmenov	Bulgaria	23.5
Mehmet Burak Yılmaz	Turkey	23.5
Andrea Montanari	Italy	23.45
Slaven Garaj	Croatia	23.15
Jaroslaw Potiuk	Poland	22.95
Nathaniel Kuang Chern Ng	Singapore	22.7
Boyko Zlatev	Bulgaria	22.6
Marco Van Leeuwen	Netherlands	22.55
Jemmy Widjaja	Indonesia	21.85
Jaehyuk Choi	Korea	21.85
Paul Tupper	Canada	21.75
Marko Karlusic	Croatia	21.75
Davíð Þór Bragason	Iceland	21.75
Ewald Rossl	Austria	21.75
Daniel Svensek	Slovenia	21.75
Damir Pajic	Croatia	21.5
Taner Akbas	Turkey	21.5
Quang Long Ngô	Vietnam	21.5
Nujeh Alireza*	Iran	21.25
Khoong Hong Khoo	Singapore	21.1
Miglius Alaburda	Lithuania	21
Sirisin Janrungautai	Thailand	21
Andy Gefferth	Hungary	20.95
Bagheri Rahim*	Iran	20.83
John Fitzgerald	Australia	20.8
Daniel Prusa	Czech Republic	20.8
Christian Pfaffel	Austria	20.75
Franz Diwoky	Austria	20.5
Andrzej Komisarski	Poland	20.5
Hans Bornefalk	Sweden	20.5
Kang Looi Choo	Singapore	20.15

* unofficial score

Special Prizes

Top student of each country

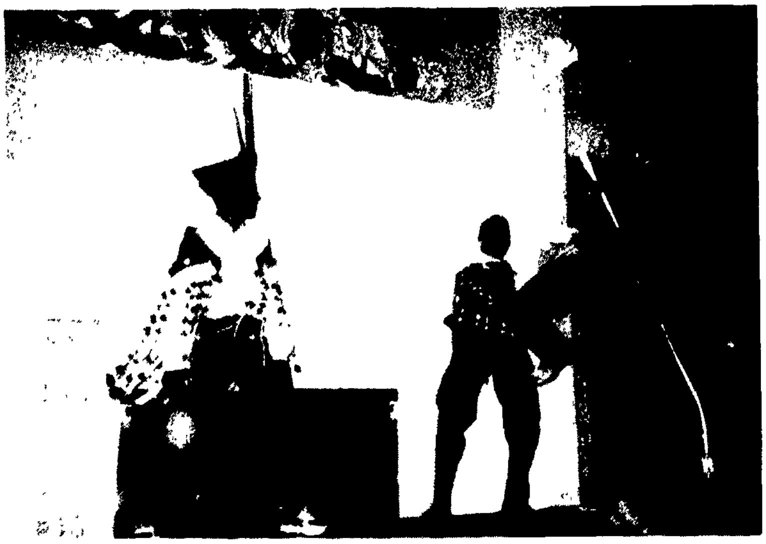
Australia:	Venkatesh, Akshay
Austria:	Rossl, Ewald
Belgium:	Vandenhove, Tom
Bulgaria:	Kassabov, Martin
Canada:	Kry, Robert
China:	Zhang, Junan
Colombia:	Massey, Ibrahim
Croatia:	Garaj, Slaven
Cuba:	Campa, Erwin Portuondo
Cyprus:	Tofaris, Georgios
Czech Republic:	Kocka, Tomas
Estonia:	Kaldalu, Andrus
Finland:	Voipio, Ville
Germany:	Pfeiffer, Harald
Great Britain:	Machacek, Antonin
Greece:	Vetsikas, Ioannis
Hungary:	Katz, Sandor
Iceland:	Bragason, Daviopor
Indonesia:	Gunawan, Oki
Iran:	Shahidzadeh, Alireza*
Italy:	Galimberti, Marco
Korea:	Kim, Yongjik
Kuwait:	Gheloum, Abdul Aziz
Lithuania:	Anisimovas, Egidijus
Mexico:	Pelayo, Rodrigo
Netherlands:	Van Lankvelt, Frank
Norway:	Natvig, Jostein
Philippines:	Figuerres, Archimedes
Poland:	Szyposzynski, Mariusz
Romania:	Ciocirlie, Calin
Russia:	Belenov, Roman
Singapore:	Ng, Chee We
Slovakia:	Gaj, Milos
Slovenia:	Veble, Gregor
Spain:	Sanchez Quintanilla, Miguel Angel
Suriname:	Chin Joe, Foek

Sweden:	Larsson, Erik
Thailand:	Janrungautai, Sirisin
Turkey:	Adem, Salih
Ukraine:	Jakupov, Renat
United States:	Jens, Dean
Viet Nam:	Thai, Thanh Minh

Additional Special Prizes

Theory Problem #2	Lajos Molnar	Hungary
	Andrzej Komisarski	Poland
Theory Problem #3	Thomas Dent	Great Britain
Experimental Problem #1	Gábor Veres	Hungary
	Ari Eiriksson	Iceland
Experimental Problem #2	Andras Major	Germany

EPS Award for the best balance of theory and practical:	Linbo Li	China



The generosity of the sponsors of the Olympiad afforded students and leaders with the following gifts and prizes:

Duracell beach bag with sunglasses, radio, towel, hat and water bottle
Duracell flashlights and batteries
Busch Gardens T-shirts
Busch Gardens Tote bags with accelerometer, stopwatch and calculator
Metrologic lasers for the top student in every country and that student's high school teacher.
Texas Instrument TI 85 graphing calculators for Gold Medalists
Texas Instrument TI 68 programmable scientific calculators for the Silver and Bronze medalists
Wiley's book *Flying Circus of Physics* (autographed by Jearl Walker)
Merck pens
College T-shirts
Quantum magazine
Travel mugs from experimental exam
Olympiad satchel
Olympiad T-shirts
Medals and certificates of participation

EPILOGUE

These eight days in Williamsburg culminate months of hard work in our many nations with a flurry of studying, testing, organizing, socializing and anticipating. The Olympiad is an extraordinary process of developing an international community of scholars across generations, scholars with diverse languages, political and social traditions but with a commitment to one another and to intellectual excellence.

We convene for multiple purposes, are committed to cooperation and to competition and draw upon the contributions of the young and the old. We continue traditions of the centuries and we establish the communities of the future. Ours is a celebration of excellence and accomplishment, a convening of generations from across the artificial boundaries of the world.

Physics is our agenda. The future is our vision. We celebrate the hope of excellence and the promise of peace. The XXIV International Physics Olympiad is our contribution to those dreams.

We wish you a year of prosperity and happiness and we shall continue our journey in China at the XXV International Physics Olympiad.

Bernard V. Khoury
Executive Officer, AAPT

PART 2

The Examination

LASER FORCES ON A TRANSPARENT PRISM

FORCES EXERCES PAR UN LASER SUR UN PRISME TRANSPARENT

KRACHTEN T.G.V. EEN LASERBUNDEL OP EEN TRANSPARANT PRISMA

СИЛИ, С КОИТО ЛАЗЕРНО ЛЪЧЕНИЕ ДЕЙСТВА НА ПРОЗРАЧНА ПРИЗМА

LASEROVÉ SÍLY V PRŮHLEDNÉM HRANOLU

FUERZAS DEBIDAS AL LASER EN UN PRISMA TRANSPARENTE

LASERIN VOIMAVAIKUTUS LÄPINÄKYVÄÄN PRISMAAN

LÉZERFÉNY ERŐHATÁSA ÁTLÁTSZÓ PRIZMÁRA

VERKUN LEYSIGEISLA Á GEGNSÆJAN ÞRÍSTRENDING

GAYA LASER PADA PRISMA TRANSPARAN

نیروی لیزری بر یک منشور شفاف

투명한 프리즘 위에 작용하는 레이저 광의 힘

قوة الليزر على المنشور الشفاف

LAZERIO JĖGOS, VEIKIANČIOS SKAIDRIĄJĄ PRIZMĘ

Teoretisk oppgave 2. Laserkrefter på et gjennomsiktig prisme

ODDZIAŁYWANIE MECHANICZNE ŚWIATŁA LASEROWEGO NA PRZEZROCZYSTY PRYZMAT

Problema II - Forte laser ce actioneaza asupra unei prisme transparente.

ЛАЗЕРНЫЕ СИЛЫ, ДЕЙСТВУЮЩИЕ НА ПРОЗРАЧНУЮ ПРИЗМУ

2. úloha: Silové účinky lasera na priezračný hranol

Problem 2 Krafter från en laser på ett genomskinligt prisma

SAYDAM BİR PRİZMA ÜZERİNDEKİ LAZER KUVVETİ

Những lực mà một laze tác dụng lên một lăng kính trong suốt

ΔΥΝΑΜΕΙΣ ΠΟΥ ΑΣΚΕΙ ΔΕΣΜΗ ΑΚΤΙΝΩΝ LASER ΠΑΝΩ ΣΕ ΔΙΑΦΑΝΕΣ ΠΡΙΣΜΑ

Sila laserske svetlobe na prizmo

LASER DJELUJE SILOM NA PROZIRNU PRIZMU

激光对透明棱镜的作用力

แรงที่แสงเลเซอร์กระทำต่อปริซึมโปร่งใส

PROBLEMA N 2 FORZE LASER SU UN PRISMA TRASPARENTE

Kräfte eines Lasers auf ein transparentes Prisma

COUNTRY : ________________

XXIV INTERNATIONAL PHYSICS OLYMPIAD

WILLIAMSBURG, VIRGINIA, U.S.A.

THEORETICAL COMPETITION

July 12, 1993

Time available: 5 hours

READ THIS FIRST!

INSTRUCTIONS:

1. Use only the pen provided.
2. Use only the marked side of the paper.
3. Begin each problem on a separate sheet.
4. Write at the top of each and every page:

   - The number of the problem
   - The number of the page of your solution in each problem
   - The total number of pages in your solution to the problem.

   Example (for Problem 1): 1 1/4; 1 2/4; 1 3/4; 1 4/4.

General Tabulated Information

Quantity	Symbol	Value
Earth's mean radius	R_E	6.4×10^{6} m.
acceleration due to gravity	g	9.8 m s^{-2}.
Newtonian gravitational constant	G	6.67×10^{-11} N m^2 kg^{-2}.
permittivity of vacuum	ε_0	8.85×10^{-12} C^2 N^{-1} m^{-2}.
permeability of vacuum	μ_0	8.85×10^{-7} N A^{-2}.
speed of light in vacuum (or air)	c	3.00×10^{8} m s^{-1}.
elementary charge	e	1.60×10^{-19} C.
mass of electron	m_e	9.11×10^{-31} kg.
mass of proton	m_p	1.67×10^{-27} kg
Planck constant	h	6.63×10^{-34} J s.
Avogadro constant	N_A	$6,02 \times 10^{23}$ mol^{-1}.
Boltzmann constant	k	1.38×10^{-23} J K^{-1}.
molar gas constant	R	8.31 J mol^{-1} K^{-1}.

ATMOSPHERIC ELECTRICITY

From the standpoint of electrostatics, the surface of the Earth can be considered to be a good conductor. It carries a certain total charge Q_0 and an average surface charge density σ_0.

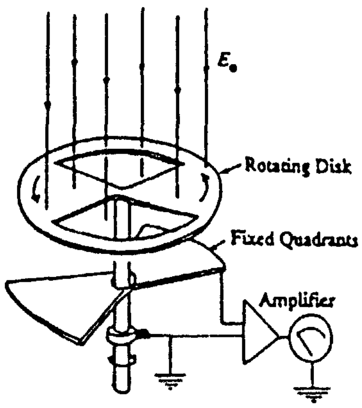
1) Under fair-weather conditions, there is a downward electric field, E_0, at the Earth's surface equal to about 150 V/m. Deduce the magnitude of the Earth's surface charge density and the total charge carried on the Earth's surface.

2) The magnitude of the downward electric field decreases with height, and is about 100 V/m at a height of 100 m. Calculate the average amount of net charge per m³ of the atmosphere between the Earth's surface and 100 m altitude.

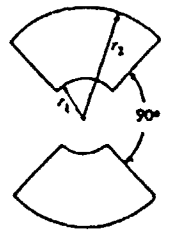
3) The net charge density you have calculated in (2) is actually the result of having almost equal numbers of positive and negative singly-charged ions per unit volume (n_+ and n_-). Near the Earth's surface, under fair-weather conditions, $n_+ \approx n_- \approx 6 \times 10^8$ m^{-3}. These ions move under the action of the vertical electric field. Their speed is proportional to the field strength:

$$v \approx 1.5 \times 10^{-4} \cdot E,$$

where v is in m/s and E in V/m. How long would it take for the motion of the atmospheric ions to neutralize half of the Earth's surface charge, if no other processes (e.g. lightning) occurred to maintain it?



4) One way of measuring the atmospheric electric field, and hence σ_0, is with the system shown in the diagram. A pair of metal quadrants, insulated from ground but connected to each other, are mounted just underneath a grounded uniformly rotating disk with two quadrant-shaped holes cut in it. (In the diagram, the spacing has been exaggerated in order to show the arrangement.) Twice in each revolution the insulated quadrants are completely exposed to the field, and then (1/4 of a period later) are completely shielded from it. Let T be the period of revolution, and let the inner and outer radii of the insulated quadrants be r_1 and r_2 as shown.



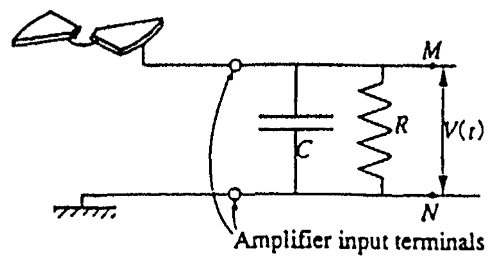
(Continued on next page)

Take $t = 0$ to be an instant when the insulated quadrants are completely shielded.

Obtain expressions that give the total charge $q(t)$ induced on the upper surface of the insulated quadrants as a function of time between $t = 0$ and $t = T/2$, and sketch a graph of this variation.

[The effects of the atmospheric ion current can be ignored in this situation.]

(5) The system described in (4) is connected to an amplifier whose input circuit is equivalent to a capacitor C and a resistor R in parallel. (You can assume that the capacitance of the quadrant system is negligible compared to C.) Sketch graphs of the form of the voltage difference V between the points M and N as a function of t during one revolution of the disk, just after it has been set into rotation with period of revolution T, if:



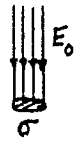
a) $T = T_a \ll CR$;
b) $T = T_b \gg CR$.

[Assume that C and R have fixed values; only T changes between situations (a) and (b).] Obtain an expression for the approximate ratio, V_a/V_b, of the largest values of $V(t)$ in cases (a) and (b).

6) Assume that $E_0 = 150$ V/m, $r_1 = 1$ cm, $r_2 = 7$ cm, $C = 0.01$ μF, $R = 20$ MΩ, and suppose that the disk is set into rotation at 50 revolutions per second.

Approximately, what is the largest value of V during one revolution in this case?

Theoretical Problem 1 -- Solution



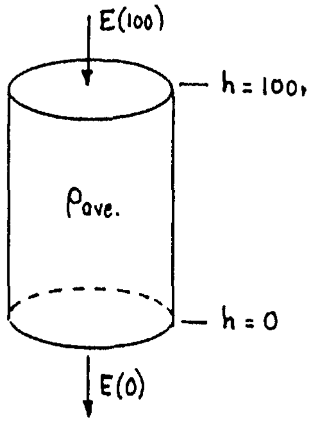
1) By Gauss' law, $\sigma = \varepsilon_0 E_0$.

$$\therefore\ \sigma = -8.85\ 10^{-12} \times 150$$

$$\approx -1.3 \times 10^{-9}\ \mathrm{C/m^2}.$$

$$Q = 4\pi R^2 \sigma = 4\pi \times (6.4 \cdot 10^6)^2 \times 1.3 \cdot 10^{-9} = -6.7 \cdot 10^5\ \mathrm{C}.$$

2) Consider a cylinder of cross-section A with faces at heights of 0 and 100 m.



By Gauss' law, $E(0)\,A - E(100)\,A = q_{enclosed}/\varepsilon_0$

$$= \rho_{ave.} \times (100A)/\varepsilon_0.$$

$$\therefore\ \rho_{ave.} = \frac{\varepsilon_0[E(0) - E(100)]}{100}$$

$$= \frac{8.85\ 10^{-12} \times 50}{100} \approx 4.4 \times 10^{-12}\ \mathrm{C/m^3}.$$

3) If a conductor contains n charges per unit volume, each with charge q and travelling with speed v, the current per unit area (j) is given by:

$$j = nqv.$$

Here, we have both positive and negative charges ($\pm e$). Clearly, with a downward electric field, the positive charges move downward and the negative charges move upward.

In the situation as described, only the positive charges can contribute to neutralization of the Earth's surface charge. Hence we have (taking downward as the positive direction for this purpose):

$$j = n_+ e\, v$$

$$\approx (6 \cdot 10^8) \times (1.6 \cdot 10^{-19}) \times (1.5 \cdot 10^{-4}\, E)$$

$$= 1.44 \times 10^{-14}\, E.$$

Now j is the rate of change ($d\sigma/dt$) of the surface charge density σ, and E (if defined as positive downward) is equal to $-\sigma/\varepsilon_0$. Thus the above equation can be written:

$$\frac{d\sigma}{dt} = -1.44 \cdot 10^{-14} \frac{\sigma}{\varepsilon_0} = -\frac{1.44 \cdot 10^{-14}}{8.85 \cdot 10^{-12}}\sigma = -1.63 \cdot 10^{-3}\sigma \approx -\frac{1}{600}\sigma.$$

This is just like the equation of radioactive decay. Its solution is an exponential decrease of σ with time:

$$\sigma(t) = \sigma_0\, e^{-t/\tau}, \quad \text{with } \tau \approx 600\ \text{sec.}$$

Putting $\sigma(t) = \sigma_o/2$ then gives $t = \tau \ln 2 = 0.693 \times 600 \approx 415$ sec $\approx$ 7 min.

[A simpler approximate solution is to assume that j remains constant at its initial value j_0:

$$j_0 = 1.44 \cdot 10^{-14} E_0 = 1.44 \cdot 10^{-14} \times 150 \approx 2.15 \times 10^{-12} \text{ A/m}^2.$$

With $|\sigma_0| = 1.3 \; 10^{-9}$ C/m^2 from part 1, we would then put:

$$|\sigma_o/2| = j_0 \times t, \text{ giving } t = (0.65 \cdot 10^{-9})/(2.15 \cdot 10^{-12}) \approx 300 \text{ s} = 5 \text{ min.}]$$

4) If $t = 0$ is an instant at which the insulated quadrants are completely shielded, we have the following relations:

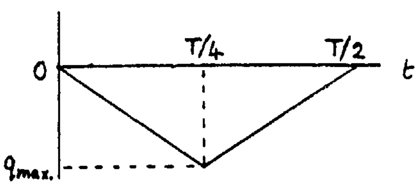
For $0 \le t \le \frac{T}{4}$, $q(t) = -2\pi(r_2^2 - r_1^2)\varepsilon_0 E_0 \frac{t}{T}$.

For $\frac{T}{4} < t \le \frac{T}{2}$, $q(t) = -\pi(r_2^2 - r_1^2)\varepsilon_0 E_0 \left(1 - \frac{2t}{T}\right)$.

Corresponding variations occur during all the succeeding pairs of quarter-cycles.

The maximum (negative) induced charge is given by:

$$q_{\text{max.}} = -\frac{\pi}{2}(r_2^2 - r_1^2)\varepsilon_0 E_0.$$

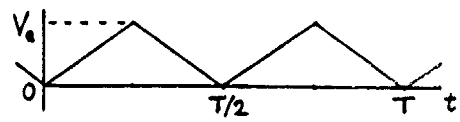


5) This question can be discussed without making a full circuit analysis. One only needs to realize that the rate of flow of charge into the amplifier is divided into a rate of charging of the capacitor, $C \, dV/dt$, and a conduction current, V/R, through the resistor. There are then two extreme situations, depending on whether the amount of charge lost by leakage during one quarter-period is small or large compared to CV.

(a) If $CV \gg (V/R) \times (T/4)$ -- i.e., $T = T_a \ll CR$ -- very little of the charge is carried away through R during the time $T/4$. Thus, when the insulated quadrants are charged negatively through induction, an almost equal *positive* charge is given to C. Thus $V(t)$ rises almost linearly with t between $t = 0$ and $t = T/4$, and then decreases almost linearly by an equal amount between $t = T/4$ and $t = T/2$. In this case,

$$V_{\text{max.}} = V_a \approx \frac{|q_{\text{max.}}|}{C},$$

where $q_{\text{max.}}$ has the value obtained in part 4.*



(b) If, however, $T = T_b \gg CR$ -- i.e., $CR \ll T_b$ -- most of the charge is quickly carried away through R. A constant positive current flows through R when the magnitude of q is increasing, and an equal negative current when the magnitude of q is decreasing. The size

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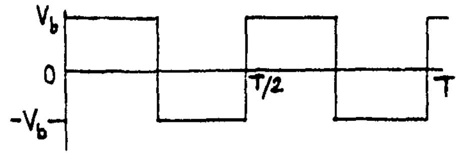
*Note: Ultimately (unless CR is infinite) the form of V_a will become a sawtooth varying symmetrically between $\pm \, q_{\text{max.}}/2C$. The statement of the problem avoids this complication by specifying that V is measured *just after* the rotation has begun.

of this current is approximately equal to $|q_{max.}|/(T_b/4)$. The resulting voltage across R is approximately constant during each quarter-period, and is alternately positive and negative. In this case,

$$V_{max.} = V_b \approx \frac{4\,q_{max.}R}{T_b}.$$



Putting these results together, we see that:

$$\frac{V_a}{V_b} \approx \frac{T_b}{4CR}.$$

6) We have $CR = 10^{-8} \times 2\,10^{7} = 0.2$ s, and $T = 1/50 = 0.02$ s.
Thus $CR = 10 \times T$, which satisfies the criterion $CR \gg T$.
Therefore we can use the solution 5(a) above.
We have $A_{max.} = \frac{\pi}{2}(7^2 - 1^2) = 75\ \text{cm}^2 = 7.5 \times 10^{-3}\ \text{m}^2$.
$E_o = 150$ V/m $\rightarrow$ $\sigma = \varepsilon_o E_o \approx 1.33 \times 10^{-9}$ C/m^2 (as in part 1).
$\therefore\ q_{max.} = 1.33 \cdot 10^{-9} \times 7.5\ 10^{-3} \approx 1.0 \times 10^{-11}$ C,

and so $V_{max.} \approx \dfrac{q_{max.}}{C} \approx \dfrac{1.0 \times 10^{-11}}{1.0 \times 10^{-8}} = 10^{-3}\ \text{V} = 1$ mV.

Theoretical Problem 1: Grading Scheme

Part 1.	1 point	(1/2 point for σ_0, 1/2 point for Q)
Part 2.	1 point	
Part 3.	2 points	(1/2 point for recognizing $j = nev$; 1/2 point for recognizing $j = d\sigma/dt$; 1/2 point for getting $\sigma(t) = \sigma_0\, e^{-t/\tau}$; 1/2 point for final numerical answer.) [1 point maximum for using $t = \sigma_0/2j_0$.]
Part 4.	1-1/2 points	(1/2 point for each equation; 1/2 point for graph.)
Part 5.	3-1/2 points	(1 point for correct graphical form of (a); 1 point for correct graphical form of (b); 1-1/2 points for correct evaluation of V_a/V_b.)
Part 6.	1 point	(1/2 point for recognizing that $T \ll CR$; 1/2 point for final answer)

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2. 1.00
3. 2.00
4. 0.75
5. 3.50
6. 1.00

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total

1. 解:

(1) 地球是良导体，电荷都分布在表面。

$Q_0 = 4\pi R_E^2 \sigma_0$

表面电场竖直向下，为负值 = is negative

$E = \frac{1}{4\pi\varepsilon_0}\frac{Q_0}{R_E^2} = \frac{\sigma_0}{\varepsilon_0}$

sign

$\sigma_0 = \varepsilon_0 \cdot E = 8.85\times10^{-12}\times(-150) = (-)1.328\times10^{-9}\ (C\cdot m^{-2})$ $\frac{1}{2}$

$Q_0 = 4\pi R_E^2\sigma_0 = 4\pi\times(6.4\times10^6)^2\times(-)1.328\times10^{-9} = 6.83\times10^5\ (C)$ $\frac{1}{2}$

1

(2) $100\,m \ll R_E = 6.4\times10^6\,m$

则认为100米下之大气为薄球壳形状。 $h = 100m$

100米之下总电量 $Q_{100m} = Q_0 + 4\pi R^2 h\cdot\bar{\rho}$

$E' = \frac{1}{4\pi\varepsilon_0}\frac{Q_{100m}}{(R_E+h)^2} = \frac{1}{4\pi\varepsilon_0}\frac{Q_0+4\pi R^2 h\bar{\rho}}{(R_E+h)^2}$

~~$= \frac{1}{4\pi\varepsilon_0}(Q_0+4\pi R^2 h\bar{\rho})(\frac{1}{R_E^2}+\frac{2h}{R_E^3})$~~

$h \ll R$ $(R_E+h)^2 \simeq R_E^2$

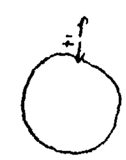
$E' = E + \frac{\bar{\rho}h}{\varepsilon_0}$

1

$$\bar{\rho} = \frac{(E'-E)\varepsilon_0}{h} = \frac{(-100)-(-150)\times 8.85\times 10^{-12}}{100} = 4.425\times 10^{-12}\ (C/m^3).$$

(3) 考虑地面附近，Q为地球表面的电量

电场 $E=\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q}{R_E^2}$（离地面很近空气中电荷不计）。向下。



正离子向下运动，负离子向上运动。

则地面电量被正电荷中和

$$dQ = e\cdot n_+\cdot 4\pi R_E^2 |v_+| dt$$

$$v_+ = 1.5\times 10^{-4} E \qquad 令 k = 1.5\times 10^{-4}\ m^2/(V\cdot s)$$

$$dQ = e n_+ \cdot 4\pi R_E^2 \cdot \left|k\cdot\frac{1}{4\pi\varepsilon_0}\frac{Q}{R_E^2}\right| dt$$

$$dQ = e n_+ \cdot \frac{k}{\varepsilon_0}(-Q)\, dt$$

积分得 $\quad Q = Q_0\, e^{-\frac{e n_+ k}{\varepsilon_0} t}$

当 $Q = \frac{1}{2}Q_0$ 时

$$t = \frac{\varepsilon_0 \ln 2}{e n_+ k} = \frac{8.85\times 10^{-12}\times \ln 2}{1.60\times 10^{-19}\times 6\times 10^{8}\times 1.5\times 10^{-4}} = 426\ (s)$$

以上解答，假设 n_+ 为定值，这是合理的，由于热运动，分子热散失

了保持 n_+ 为定值（只要大气中有足够的正离子来补充）。$v = kE$ 是漂移速度

$v << \bar{v}_i = \sqrt{\frac{8kT}{\pi m}}$

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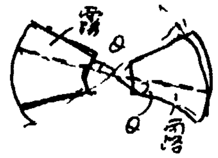
(4) (0.75) 被屏蔽的部分(表面) $E=0$. 故 $\sigma=\varepsilon E=0$ (E向上为正)

而未被屏蔽部分 $\sigma=\varepsilon_0 E_0$

本题中 $t=0$, 全屏蔽

t时 未屏蔽面积 $\cancel{S=2\times\frac{1}{2}(r_2^2-r_1^2)\cdot t\cdot\frac{2\pi}{T}=(r_2^2-r_1^2)}$

图中 $\theta=t\cdot\frac{2\pi}{T}$.



$S=2\cdot\frac{1}{2}(r_2^2-r_1^2)\theta=(r_2^2-r_1^2)\frac{2\pi}{T}\cdot t$

故 $Q=\sigma\cdot S=-\varepsilon_0 E_0\cdot(r_2^2-r_1^2)\frac{2\pi}{T}\cdot t$

negative sign

($\frac{1}{4}$

for $\frac{T}{4}<t<\frac{T}{2}$ $Q(t)=$? graph?

(5) (3.5) 电容C上通过的电流 $I_C=\frac{dQ}{dt}=C\cdot\frac{dU}{dt}$.

电阻上通过的电流 $I_R=\frac{U}{R}$.

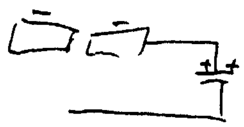
令 $\frac{dU}{dt}=\frac{U}{T}$. 则 $\frac{I_C}{I_R}=\frac{CR}{T}$.

(6). 当 $T\ll CR$ 时 $I_C\gg I_R$

相当于只连接一电容. 屏蔽时电容上电量为零(如不然将在以后的时刻也会通过R放电. 我们只讨论稳定的状态)

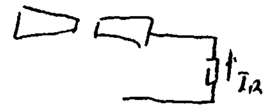
电荷守恒,有 $Q_C=-Q$ ← steady state

$V_{MN}=V(t)=-\frac{Q}{C}=\cancel{\frac{\varepsilon_0 E_0(r_2^2-r_1^2)}{C}\frac{2\pi}{T}t}$



(b). 当 $T >> CR$ 时 $I_C << I_R$

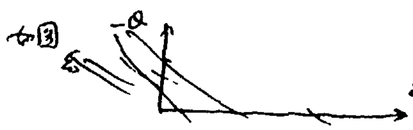
相当于只接一个电阻

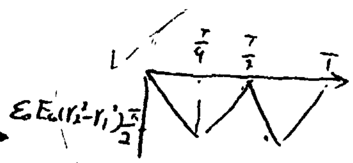


$I_R = \frac{dQ}{dt}$. $V(t) = -I_R R$

在 t 从 0 到 T 之间 Q 为以下表示

如图

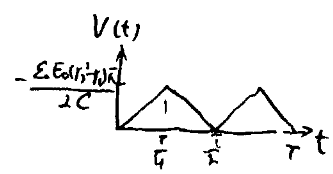




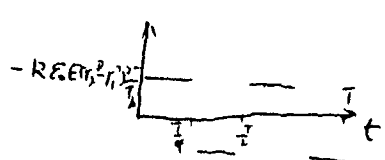
即

$$Q = \varepsilon_0 E_0 (r_2^2 - r_1^2)\frac{2\pi}{T} \begin{cases} \times t & 0 \le t < \frac{T}{4} \\ \times(\frac{T}{2} - t) & \frac{T}{4} \le t < \frac{T}{2} \\ \times(t - \frac{T}{2}) & \frac{T}{2} \le t < \frac{3T}{4} \\ \times(T - t & \frac{3T}{4} \le t < T \end{cases}$$

则. a) 中 $V(t) = -\frac{Q}{C}$



b) 中 $$V(t) = -R\varepsilon_0 E(r_2^2 - r_1^2)\frac{2\pi}{T_b} \begin{cases} \times(-1) & 0 \le t < \frac{T}{4} \quad \frac{T}{2} \le t < \frac{3T}{4} \\ \times 1 & \frac{T}{4} \le t < \frac{T}{2} \quad \frac{3T}{4} \le t < T \end{cases}$$



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最大值 $V_a = -\frac{\varepsilon_0 E_0 (r_2^2 - r_1^2)\pi}{2C}$ $\frac{1}{2}$

$V_b = -R\varepsilon_0 E_0 (r_2^2 - r_1^2)\frac{2\pi}{T_b}$ $\frac{1}{2}$

$\frac{V_a}{V_b} = \frac{T_b}{4RC}$ $\frac{1}{2}$

(b) $\frac{dQ}{dt} = I = I_C + I_R = -C\cdot\frac{dV}{dt} - \frac{1}{R}V$

$V(t)$ 的图象大致如右

(b) 1)

$T = \frac{1}{50}s = 0.02s$

$RC = 20M\Omega \times 0.01\mu F = 0.2s$

故 RC 比 T 大一个数量级

作为零级近似 当作 $RC >> T$. $\frac{1}{2}$

则 $V_{max} = -\frac{\varepsilon_0 E_0 (r_2^2 - r_1^2)\pi}{2C}$

修正: 从0到 $\frac{T}{4}$ 内.

通过 R 之电量, $Q_R = -\frac{V_{max}}{2R}\cdot\frac{T}{4}$.

设电容上有 Q_R 是 R 传过去的 则

$$Q_{R} + Q_{C_{max}} = Q_{max}$$

$$-\frac{V_{max}}{2R}\frac{T}{4} - C\,V_{max} = Q_{max},$$

故 $$V_{max} = -\frac{\varepsilon_0 E_0 (r_2^2 - r_1^2)\frac{\pi}{2}}{\frac{T}{8R} + C}$$

$$= -\frac{8.85\times10^{-12}\times(-100)\times((7\times10^{-2})^2-(1\times10^{-2})^2)\times\frac{\pi}{2}}{\frac{0.02}{8\times20\times10^{6}} + 0.01\times10^{-6}}$$

$$= 0.989\times10^{-3}\ (V)$$

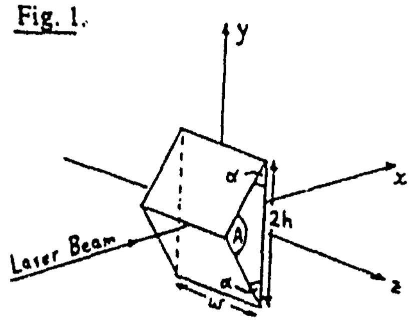
V最大值约 0.989 mV

LASER FORCES ON A TRANSPARENT PRISM

By means of refraction a strong laser beam can exert appreciable forces on small transparent objects. To see that this is so, consider a small glass triangular prism with an apex angle $A = \pi - 2\alpha$, a base of length $2h$ and a width w. The prism has an index of refraction n and a mass density ρ.

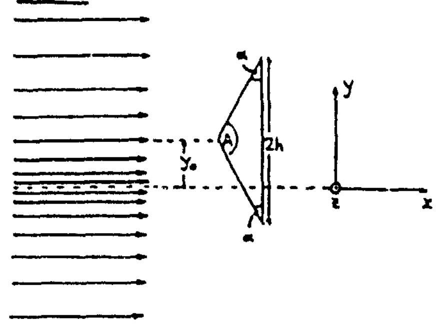
Suppose that this prism is placed in a laser beam travelling horizontally in the x direction. (Throughout this problem assume that the prism does not rotate, i.e., its apex always points opposite to the direction of the laser beam, its triangular faces are parallel to the xy plane, and its base is parallel to the yz plane, as shown in Fig. 1.) Take the index of refraction of the surrounding air to be $n_{air} = 1$. Assume that the faces of the prism are coated with an anti-reflection coating so that no reflection occurs.

Fig. 1.



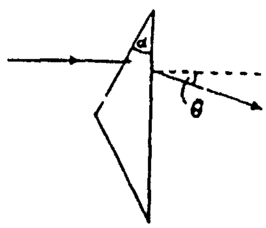
The laser beam has an intensity that is uniform across its width in the z direction but falls off linearly with distance y from the x axis such that it has a maximum value of I_0 at $y = 0$ and falls to zero at $y = \pm 4h$ (Fig. 2). [Intensity is power per unit area, e.g. expressed in W m^{-2}.]

Fig. 2.



1) Write equations from which the angle θ (see Fig. 3) may be determined (in terms of α and n) in the case when laser light strikes the upper face of the prism.

Fig. 3.



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2) Express, in terms of I_0, θ, h, w and y_0, the x and y components of the net force exerted on the prism by the laser light when the apex of the prism is displaced a distance y_0 from the x axis where $|y_0| \leq 3h$.

Plot graphs of the values of the horizontal and vertical components of force as functions of vertical displacement y_0.

3) Suppose that the laser beam is 1 mm wide in the z direction and 80 µm thick (in the y direction). The prism has $\alpha = 30°$, $h = 10$ µm, $n = 1.5$, $w = 1$ mm and $\rho = 2.5$ g cm^{-3}. How many watts of laser power would be required to balance this prism against the pull of gravity (in the -y direction) when the apex of the prism is at a distance $y_0 = -h/2$ (= -5 µm) below the axis of the laser beam?

4) Suppose that this experiment is done in the absence of gravity with the same prism and a laser beam with the same dimensions as in (3), but with $I_0 = 10^8$ W m^{-2}. What would be the period of oscillations that occur when the prism is displaced and released a distance $y = h/20$ from the center line of the laser beam?

Theoretical Problem 2 -- Solution

1. This is a simple problem in geometry and Snell's Law

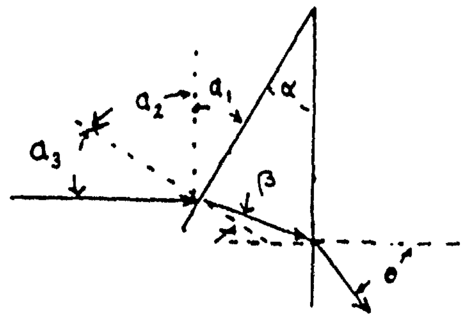

Figure 1: Refraction through a wedge.

The angle of incidence $a_3 = \alpha$ because $a_1 = \alpha$ and $a_1 + a_2 = a_2 + a_3 = 90°$ The angle β is found from Snell's law $\sin\alpha = n\sin\beta$. The angle of incidence on the base is

$$\frac{\pi}{2} - (\pi - \alpha - (\frac{\pi}{2} - \beta)) = \alpha - \beta$$

from which it follows that

$$\sin\theta = n\sin(\alpha - \beta)$$

implying that

$$\theta = \sin^{-1}\left[n\,\sin\left(\alpha - \sin^{-1}\left(\frac{\sin\alpha}{n}\right)\right)\right]$$

2. The force on the prism is equal and opposite to the rate of change of momentum of the laser light passing through it. To analyze this, consider the momentum changes of the laser light incident on the upper half of the prism.

   Think of the laser beam as delivering to the upper half of the prism r_u photons per second parallel to the x axis. If the energy of a photon is E, then its momentum is $\vec{p}_i = \frac{E}{c}\,\hat{\imath}$, and a photon leaving the prism at an angle θ to the x axis will differ in momentum from the incident photon by

$$\delta\vec{p} = \frac{E}{c}(\cos\theta - 1)\,\hat{\imath} - \frac{E}{c}\sin\theta\,\hat{\jmath}.$$

   The rate of charge of momentum of these photons will then be

$$\vec{F}_{up} = r_u\delta\vec{p} = \frac{r_u E}{c}\left[(\cos\theta - 1)\,\hat{\imath} - \sin\theta\ \ \hat{\jmath}.\right]$$

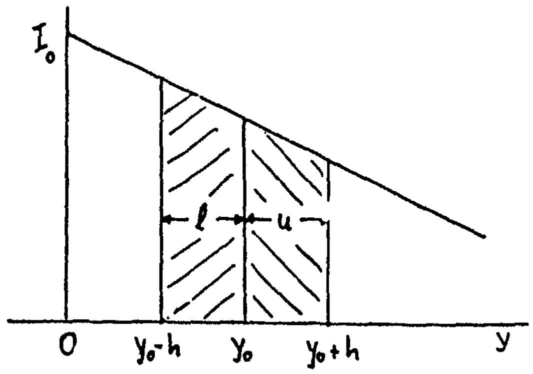

Figure 2: $\bar{I}_u$ and $\bar{I}_\ell$ when $y_0 \geq h$

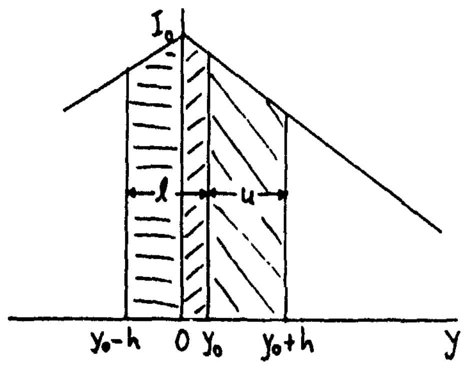

Figure 3: $\bar{I}_u$ and $\bar{I}_\ell$ when $0 < y_0 < h$

The quantity $r_u E$ is the power P_u delivered to the upper face, and the recoil force $\vec{F}_u$ produced by light refracting through the upper half of the prism will be

$$\vec{F}_u = \frac{P_u}{c}\left[(1-\cos\theta)\,\hat{\imath} + \sin\theta\,\hat{\jmath}\right].$$

A similar argument gives the force on the lower half as

$$\vec{F}_\ell = \frac{P_\ell}{c}\left[(1-\cos\theta)\,\hat{\imath} - \sin\theta\,\hat{\jmath}\right].$$

From these two results we see that the net force on the prism will be

$$\vec{F} = \frac{1}{c}\left[(P_u + P_\ell)(1-\cos\theta)\right]\,\hat{\imath} + \frac{1}{c}\left[(P_u - P_\ell)\,\sin\theta\right]\,\hat{\jmath}.$$

The angle θ can be expressed in terms of α (see answer to part 1).

To find the values of P_u and P_ℓ calculate the average intensities, $\bar{I}_u$ and $\bar{I}_\ell$, incident on each half of the prism and multiply by hw, the area of each half of the prism projected perpendicular to the laser beam. Because the intensity distribution $I(y)$ is a linear function of y, the average intensities are easily determined.

The problem states that

$$\begin{aligned} I(y) &= I_0\left(1-\frac{y}{4h}\right) && \text{for } 0 < y < +4h \\ &= I_0\left(1+\frac{y}{4h}\right) && \text{for } -4h < y < 0. \end{aligned}$$

Now suppose that the prism is lifted a distance y_0 from the x axis ($y_0 > 0$). There are two distinct cases:

(a) When $h \le y_0 \le 3h$, the whole prism is entirely in the upper half of the beam. As Fig. 2 shows, for this case the average is equal to the intensity at the center of each face which is at $y_0 + h/2$ for the upper face and at $y_0 - h/2$ for the lower one. This gives

$$\begin{aligned} \bar{I}_u = I_0\left(1-\frac{y_0+h/2}{4h}\right) &= I_0\left(\frac{7}{8}-\frac{y_0}{4h}\right) \\ \bar{I}_\ell = I_0\left(1-\frac{y_0-h/2}{4h}\right) &= I_0\left(\frac{9}{8}-\frac{y_0}{4h}\right) \end{aligned}$$

From these it follows that

$$\begin{aligned} F_x &= \frac{2hwI_0}{c}\left(1-\frac{y_0}{4h}\right)(1-\cos\theta) \\ F_y &= -\frac{hwI_0}{4c}\sin\theta. \end{aligned}$$

(b) When $0 < y_0 < h$, the lower half of the prism is partly in the lower half of the laser beam as shown in Fig. 3. Then the part of the lower half of the prism between 0 and y_0 has a fraction y_0/h of the area of the lower half of the prism and sees an average intensity

$$\bar{I}_{\ell_1} = I(y_0/2) = I_0\left(1 - \frac{y_0}{8h}\right).$$

The part between 0 and $y_0 - h$ has a fraction $1 - y_0/h$ of the area and sees an average intensity of

$$\bar{I}_{\ell_2} = I(\frac{h - y_0}{2}) = I_0\left(\frac{7}{8} + \frac{y_0}{8h}\right).$$

Putting these together we get

$$\begin{aligned} P_\ell &= hw\,\frac{y_0}{h}\bar{I}_{\ell_1} + hw\,(1 - \frac{y_0}{h})\bar{I}_{\ell_2} \\ &= hwI_0\left(\frac{7}{8} + \frac{y_0}{4h} - \frac{y_0^2}{4h^2}\right). \end{aligned}$$

The average intensity on the upper face has the same functional dependence on y_0 as in the first case. Therefore, $P_u = hwI_0\left(\frac{7}{8} - \frac{y_0}{4h}\right)$ as before.

Putting these together gives

$$\begin{aligned} P_u + P_\ell &= hwI_0\left(\frac{7}{4} - \frac{y_0^2}{4h^2}\right) \\ P_u - P_\ell &= -hwI_0\frac{y_0}{2h}\left(1 - \frac{y_0}{2h}\right) \end{aligned}$$

from which it follows that

$$\begin{aligned} F_x &= \frac{hwI_0}{c}\left(\frac{7}{4} - \frac{y_0^2}{4h^2}\right)(1 - \cos\theta) \\ F_y &= -\frac{hwI_0}{c}\frac{y_0}{2h}\left(1 - \frac{y_0}{2h}\right)\sin\theta. \end{aligned}$$

Because the intensity distribution is symmetric about the axis of the laser beam, the solutions for $y_0 < 0$ will mirror the solutions for $y_0 > 0$. Graphs of the F_x and F_y as functions of y_0 are shown in Fig. 4.

3. Both the equation and the graph of F_y show that to have $F_y > 0$ and opposite the force of gravity, y_0 must be < 0. Then to find the force necessary to support the prism against gravity, find the prism's mass, and equate the expression for the vertical component of force from the laser beam to the weight of the prism, and find I_0 for the parameters given. Use that result to find the total power in the laser beam. This

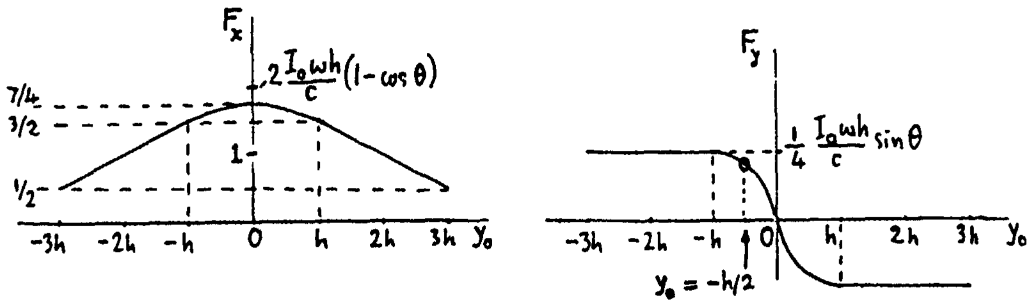

Figure 4: (a)F_x vs y_0; (b) F_y vs y_0

can be done by finding the average value $\bar{I}$ over the specified cross sectional area of the laser beam.

To find the mass of the prism first find its volume = $\tan\alpha\ h^2 w$ then

$$\begin{aligned} m &= \frac{1}{\sqrt{3}} \times (10^{-3})^2 \times .1 \times 2.5 \\ &= 1.44 \times 10^{-7} \text{ g} \\ &= 1.44 \times 10^{-10} \text{ kg;} \\ mg &= 1.42 \times 10^{-9} \text{ N} \end{aligned}$$

The solution to (2) assumed a displacement in the $y > 0$ direction, but the problem is symmetric so we can use that solution. We want the value of I_0 that satisfies

$$\frac{I_0 h w}{c} \frac{y_0}{2h} \left(1 - \frac{y_0}{2h}\right) \sin\theta = mg = 1.42 \times 10^{-9}$$

when

$$\begin{aligned} \theta &= 15.9^\circ \\ y_0 &= \frac{h}{2} \\ h &= 10 \times 10^{-6} \text{ m} \\ w &= 10^{-3} \text{ m} \end{aligned}$$

$$I_0 = \frac{3 \times 10^8 \times 1.42 \times 10^{-9}}{10^{-5} \times 10^{-3} \times .274 \times \frac{3}{16}} = 8.30 \times 10^8 \text{ W/m}^2$$

since the power P is given by $P = \bar{I} \times$ area of laser beam where $\bar{I} = \frac{I_0}{2}$. This yields

$$P = \frac{1}{2} \times 8.30 \times 10^8 \times 10^{-3} \times 80 \times 10^{-6} = 33.2 \text{ W}.$$

4. A displacement of $h/20$ corresponds to $y_0/h = .05 << 1$ so that the vertical force component is well approximated by

$$F_y = -\frac{I_0 w \sin\theta}{2c} y.$$

This is the equation of a harmonic oscillator with angular frequency

$$\omega = \sqrt{\frac{I_0 w \sin\theta}{2mc}} = \sqrt{\frac{I_0 \sin\theta}{2c\rho h^2 \tan\alpha}}.$$

Putting numbers into this gives

$$T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{2 \times 3 \times 10^8 \times 2.5 \times 10^3 \times 10^{-10} \times 1/\sqrt{3}}{10^8 \times .274}} = 11.2\times10^{-3} \text{ s}.$$

Theoretical Problem 2: Grading Scheme

Part 1.	1.5 points	
Part 2.	5 points	(2 points for obtaining expression for net force in terms of θ and powers P_u, P_l incident on upper and lower prism faces ; 1 point for finding F_x and F_y explicitly in terms of I_0, y_0 and θ for $h \le y_0 \le 3h$; 1 point for finding F_x and F_y explicitly in terms of I_0, y_0 and θ for $0 \le y_0 \le h$; 1 point for drawing appropriate graphs)
Part 3.	1.5 points	
Part 4.	2 points	

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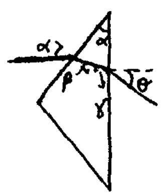
1)



$\sin\alpha = n.\sin\beta$ (1) ✓

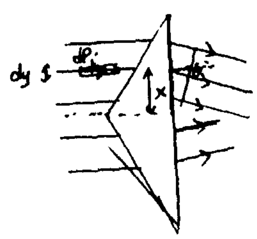
$\beta+\gamma+180-\alpha = 180$ ✓ $\Rightarrow \alpha = \beta+\gamma$ (2) ✓

$n\cdot\sin\gamma = \sin\theta$ (3)

$n \; \underbrace{\sin(\alpha-\beta)}_{\text{açılım yapılır}} = \sin\theta$ ✓ $\quad\beta$'yı α cinsinden biliyoruz

1.5

2)



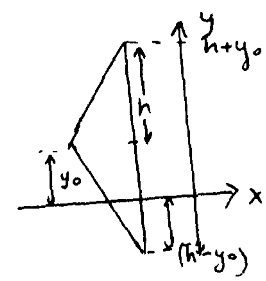
dP. dy kalınlığında ışık demetinin momentumu $dP = \frac{dE}{c} = \frac{I\cdot S\,dt}{c}$ ✓

$dP_i = \frac{dy\cdot Sw\cdot I(y)dt}{c} = P_0(y)$ ✓

$\Delta P_x = P_0\,(1-\cos\theta)$ ✓ $\quad I_y = I_0\left(1-\frac{y}{4h}\right)$

$\Delta P_y = P_0 \sin\theta$ ✓

3.5



a) $\frac{dP_x}{dt} = \int dF_x = \int \frac{I(y)\cdot dy\cdot w}{c}\,(1-\cos\theta)$

$F_x = \int_0^{h+y_0} \frac{I_0}{c} w\left(1-\frac{y}{4h}\right) dy\;(1-\cos\theta)$

continued page 3

$y<0$ için $\Rightarrow$ $I = I_0\left(1+\frac{y}{4h}\right)$

~~$F_x = \frac{I_0 w}{c}(1-\cos\theta)\left[y-\frac{y^2}{8h}\right]_{-(h-y_0)}^{h+y_0}$~~

~~$F_x = \frac{I_0 w}{c}(1-\cos\theta)\left\{h+y_0-(h-y_0)-\left[\frac{(h+y_0)^2-(h-y_0)^2}{8h}\right]\right\}$~~

~~$F_x = \frac{I_0 w}{c}(1-\cos\theta)\left[2h-\frac{\cancel{h^2}+2hy_0+\cancel{y_0^2}-\cancel{h^2}+2hy_0-\cancel{y_0^2}}{8h}\right]$~~

~~$F_x = \frac{I_0 w}{c}(1-\cos\theta)\left[2h-\frac{y_0}{2}\right]$~~

b) $F_{y_1} = \frac{I_0 w \sin\theta}{c}\int_{y_0}^{y_0+h}\left(1-\frac{y}{4h}\right)dy$ Úst kısma etkiyen kuvvet

$$= \frac{I_0 w\sin\theta}{c} \left. y - \frac{y^2}{8h}\right|_{y_0}^{y_0+h} = \frac{I_0 w \sin\theta}{c}\left[h - \frac{(\cancel{y_0^2}+2hy_0+h^2-\cancel{y_0^2})}{8h}\right]$$

√ $$= \frac{I_0 w\sin\theta}{c}\,\frac{(7h-2y_0)}{8}$$

$$F_{y_{2i}} = \underbrace{\frac{I_0 w\sin\theta}{c}}_{F_0}\int_0^{y_0}\left(1-\frac{y}{4h}\right)dy = F_0\left(y-\frac{y^2}{8h}\right) = F_0\left(y_0 - \frac{y_0^2}{8h}\right)$$

$$F_{y_{2ii}} = F_0\int_{-(h-y_0)}^{0}\left(1+\frac{y}{4h}\right)dy = F_0\left(y+\frac{y^2}{8h}\right) = F_0\left[h-y_0 + \frac{(h-y_0)^2}{8h}\right]$$

Çünkü bu bölgede y (−) dir

$$= F\left(h - y_0 - \frac{h}{8} + \frac{y_0}{4} - \frac{y_0^2}{8h}\right) = F_0\left(\frac{7h}{8} - y_0 + \frac{y_0}{4} - \frac{y_0^2}{8h}\right)$$

$$F_{y_2} = F_{y_{2i}}+F_{y_{2ii}} = F_0\left[\cancel{y_0} - \cancel{\frac{y_0^2}{8h}} + \frac{7h}{8} - \cancel{y_0} + \frac{y_0}{4} - \cancel{\frac{y_0^2}{8h}}\right]$$

$$F_{y_2} = F_0\,\frac{(7h+2y_0)}{8}$$

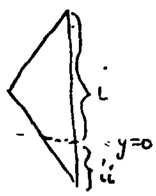
$$F_{y_{net}} = F_0\,\frac{\cancel{7h}+2y_0 - \cancel{7h} - 2y_0}{8} = F_0\,\frac{y_0}{2}$$

$y_0 +$ ise bu kuvvet aşağı doğrudur, onun için

$$\vec{F_y} = -F_0\,\frac{y_0}{2} = -\frac{I_0 w\sin\theta}{c}\,\frac{y_0}{2}$$??

Continued from a)

$$F_{x_i} = \underbrace{\frac{I_0 w}{c}(1-\cos\theta)}_{F}\left(y - \frac{y^2}{8h}\right)\Bigg|_0^{h+y_0} = F\left[h+y_0 - \frac{(h+y_0)^2}{8h}\right]$$

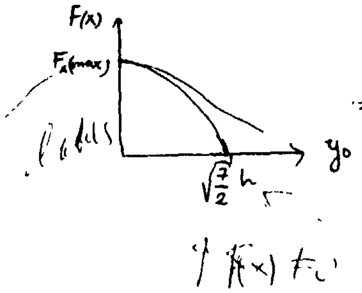


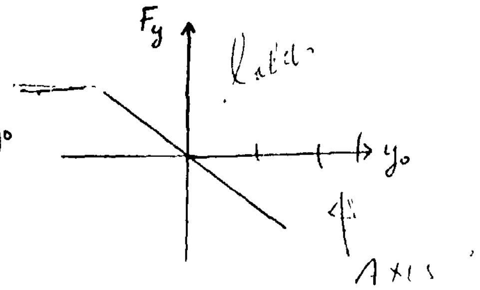
$$F_{x_{ii}} = F\left(y + \frac{y^2}{8h}\right)\Bigg|_{-(h-y_0)}^{0} = F\left[(h-y_0) + - \frac{(h-y_0)^2}{8h}\right]$$

$$= F\left(h - y_0 + \frac{y_0}{4} - \frac{h}{8} - \frac{y_0^2}{8h}\right]$$

$$F_x = F_{x_i} + F_{x_{ii}} = F\left[h + \cancel{y_0} - \frac{h}{8} - \cancel{\frac{y_0}{4}} - \frac{y_0^2}{8h} + h - \cancel{y_0} + \cancel{\frac{y_0}{4}} - \frac{h}{8} - \frac{y_0^2}{8h}\right)$$

$$F_x = F_0\left(2h - \frac{h}{4} - \frac{y_0^2}{4h}\right) = F_0\,\frac{(7h^2 - 2y_0^2)}{8h} = \frac{I_0 w}{c}(1-\cos\theta)\,\frac{(7h^2-2y_0^2)}{8h}$$





did not complete Fx, Fy for all cases

3.) $m = \rho \cdot V = \rho \cdot \frac{2h \cdot h \sin\alpha}{\cancel{2}} w = 2.5 \cdot \cancel{10^3} \cdot 10^2 \cdot 10^{-12} \cdot 0.5 \cdot \cancel{10^{-3}} = 1.25 \cdot 10^{-10}$ kg

1

$mg = \frac{I_o w \sin\theta}{c} \cdot \frac{y_o}{2}$

(1) şıkkına göre θ görülürse $\sin\theta = 0.275$ bulunur.

1.5

$1.25 \cdot 10^{-16} \cdot 9.8 = \frac{I_o \cdot 10^{-3} \cdot 0.275 \cdot 5 \cdot 10^{-6}}{3 \cdot 10^8 \cdot 2}$

$I_o = \frac{6 \cdot 1.25 \cdot 10^2 \cdot 9.8 \cdot 10^6}{5 \cdot 0.275} = 5.35 \cdot 10^8$ W/m²

$P = I_o \cdot S = 5.35 \cdot 10^8 \cdot 10^{-3} \cdot 80 \cdot 10^{-6} = 42.8$ W

4.) Prizmanın bir denge konumu vardır. Bu nokta etrafında geri çağırıcı lazer kuvveti

$F = -\frac{I_o w \sin\theta}{c} \frac{y_o}{2} = m \frac{d^2}{dt^2}(y_o)$ şeklindedir.

2.0

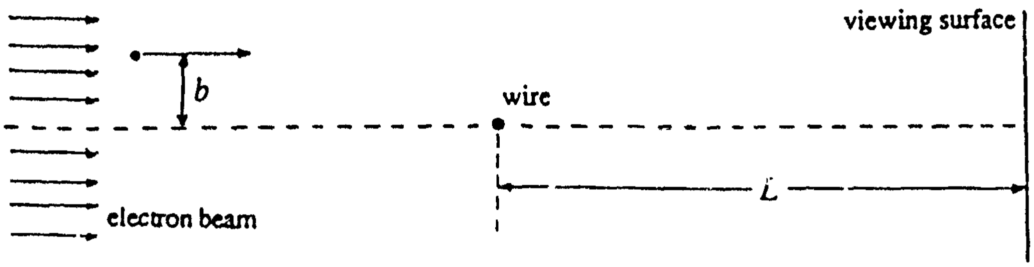
$w^2 = \frac{k}{m}$ $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{2mc}{I_o w \sin\theta}}$

$T = 2\pi\sqrt{\frac{2 \cdot 1.25 \cdot 10^{-16} \cdot 3 \cdot 10^8}{10^8 \cdot 10^{-3} \cdot 0.275}} = 5.99 \cdot 10^{-3}$ s

Theoretical Problem 3

ELECTRON BEAM

An accelerating voltage V_0 produces a uniform, parallel beam of energetic electrons. The electrons pass a thin, long, positively charged copper wire stretched at right angles to the original direction of the beam, as shown in the figure. The symbol b denotes the distance at which an electron would pass the wire if the wire were uncharged. The electrons then proceed to a screen (viewing surface) a distance L ($\gg b$) beyond the wire, as shown. The beam initially extends to distances $\pm b_{max}$ with respect to the axis of the wire. Both the width of the beam and the length of the wire may be considered infinite in the direction perpendicular to the paper.



The charged wire extends perpendicularly to the plane of the paper. The sketch is not to scale.

Some numerical data are provided here; you will find other numerical data in the table at the front of the examination:

radius of wire = r_0 = 10^{-6} m

maximum value of b = b_{max} = 10^{-4} m

electric charge per unit length of wire = q_{linear} = 4.4×10^{-11} C m^{-1}

accelerating voltage = V_0 = 2×10^4 V

length from wire to observing screen = L = 0.3 m.

Note: For parts 2 - 4, make reasonable approximations that lead to analytical and numerical solutions.

1) Calculate the electric field E produced by the wire. Sketch the magnitude of E as a function of distance from the axis of the wire.

(Continued on next page)

2) Use classical physics to calculate the angular deflection of an electron. Do this for values of the parameter b such that the electron does not strike the wire. Let θ_{final} denote the (small) angle between the initial velocity of the electron and the velocity when the electron reaches the viewing surface. Hence, calculate θ_{final}.

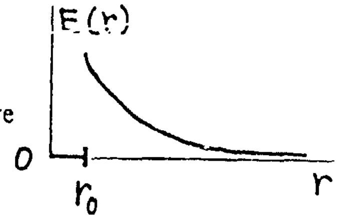
3) Calculate and sketch the pattern of impacts (i.e., the intensity distribution) on the viewing screen that classical physics predicts.

4) Quantum physics predicts a major difference in the intensity distribution (relative to what classical physics predicts). Sketch the pattern for the quantum prediction and provide quantitative detail.

Theoretical Problem 3 -- Solution

1 By symmetry, the electric field will point radially away from the wire, and its magnitude will depend only on the radius r (in cylindrical coordinates) Place an imaginary cylinder around the wire and use Gauss's law·

$$2\pi r E(r) = \frac{q_{\text{linear}}}{\varepsilon_0}$$



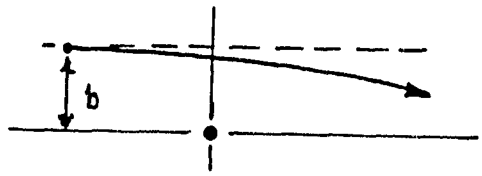
for a cylinder of radius r and unit length, provided $r \geq r_0$ Therefore

$$E(r) = \frac{q_{\text{linear}}}{2\pi r\varepsilon_0} = \frac{0\ 791}{r}\ N/C \quad \text{provided} \quad r \geq r_0$$

When $r < r_0$, the electric field is zero (because copper is a good conductor), that is, the electric field is zero inside the wire

2 The problem stated that the angular deflection is small Estimate the deflection angle θ_{final} by forming a quotient· the momentum acquired transverse to the initial velocity divided by the initial momentum

$$\theta_{\text{final}} \cong \frac{|\Delta \mathbf{p}_\perp|}{mv_0}$$



A first estimate of the transverse momentum can be made as follows

The transverse force (where it is significant) is of order $\frac{eq_{\text{linear}}}{2\pi\varepsilon_0 b}$

The (significant) transverse force operates for a time such that the electron goes a distance of order $2b$, and hence that transverse force operates for a time of order $2b/v_0$

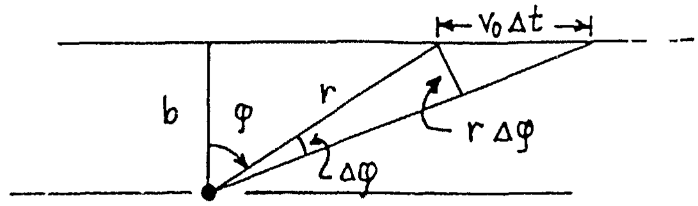
The product of force and operating time gives an estimate the transverse momentum

$$|\Delta \mathbf{p}_\perp| \cong \frac{eq_{\text{linear}}\, 2b}{2\pi\varepsilon_0 b v_0} = \frac{eq_{\text{linear}}}{\pi\varepsilon_0 v_0},$$

and so $\theta_{\text{final}} \cong \frac{eq_{\text{linear}}}{\pi\varepsilon_0 m v_0^2} = \frac{q_{\text{linear}}}{\pi\varepsilon_0 2V_0} = 3\ 96 \times 10^{-5}$ radians

after one uses energy conservation to say $\frac{1}{2}mv_0^2 = eV_0$ Note that the deflection is extremely small and that the deflection is independent of the impact parameter b Because the force between the positively charged wire and the electron is attractive, the deflection will bend the trajectory toward the wire--though only ever so slightly

A more accurate estimate can be made by setting up an elementary integration for $|\Delta \mathbf{p}_{\perp}|$, as follows. For the sake of the integration, approximate the actual trajectory by a straight line that passes the wire at distance b, as shown in the sketch.



$$|\mathbf{F}_{\perp}| = \frac{e q_{\text{linear}}}{2\pi\varepsilon_0 r}\cos\varphi \qquad v_0\,\Delta t\cos\varphi = r\,\Delta\varphi \quad \text{and so} \quad \Delta t = \frac{r\,\Delta\varphi}{v_0\cos\varphi}$$

$$|\mathbf{F}_{\perp}|\,\Delta t = \frac{e q_{\text{linear}}}{2\pi\varepsilon_0 r}\cos\varphi\,\frac{r\,\Delta\varphi}{v_0\cos\varphi} = \frac{e q_{\text{linear}}}{2\pi\varepsilon_0 v_0}\,\Delta\varphi$$

Adding up the increments in $\Delta\varphi$ over the range $-\pi/2$ to $\pi/2$ yields $|\Delta \mathbf{p}_{\perp}| = \dfrac{e q_{\text{linear}}}{2\varepsilon_0 v_0}$

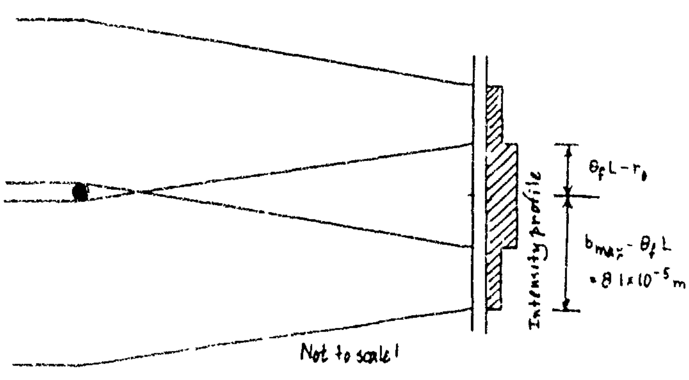
The better estimate differs from the first estimate by merely the factor [illegible]. The better estimate yields

$$\theta_{\text{final}} \cong \frac{e q_{\text{linear}}}{2\varepsilon_0 m v_0^2} = \frac{q_{\text{linear}}}{2\varepsilon_0 2 V_0} = 6.21\times10^{-5}\ \text{radians}$$

3. Most of the bending of the trajectory occurs within a distance from the wire of order b. On the scale of L, order b is very small indeed. Therefore we may approximate the trajectory by two straight lines with a kink near the wire. Thus, at the viewing surface, the transverse displacement of each trajectory is

$$\begin{pmatrix}\text{transverse}\\ \text{displacement}\end{pmatrix} = \theta_{\text{final}} L = 6.21\times10^{-5}\times 0.3 = 1.86\times10^{-5}\ \text{meter} \cong 19\,r_0 >> r_0$$

Thus the portions of the beam that pass on opposite sides of the wire have a region of overlap, as shown in the sketch.



The full width of the overlap region is

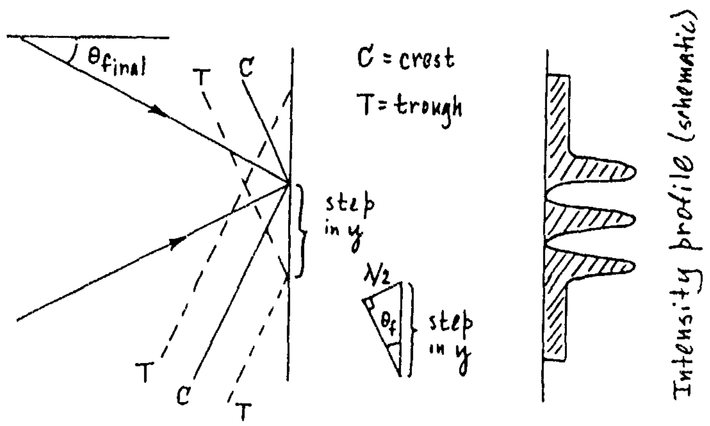
$$\begin{pmatrix} \text{full} \\ \text{width} \end{pmatrix} = 2 \times (\theta_{\text{final}} L - r_0) \cong 36\, r_0 = 36 \times 10^{-6} \quad \text{meter}$$

The density of impacts is constant within each region and doubled in the overlap region

4 Associated with the electron beam is a quantum wave pattern whose de Broglie wavelength is

$$\lambda = \frac{h}{m v_0} = \frac{h}{\sqrt{2 m e V_0}} = 8\ 68 \times 10^{-12} \quad \text{meter}$$

The de Broglie wavelength is so much smaller than the beam width $2b_{\text{max}}$ that one may ignore "single slit diffraction" effects Rather, to the right of the wire, two plane waves that travel at a fixed angle relative to each other (an angle $2\theta_{\text{final}}$) overlap and interfere In the region where, classically, the two halves of the original beam overlap, there will be interference maxima and minima



Reference to the sketch indicates that

$$\begin{pmatrix} \text{Interval between} \\ \text{adjacent constructive} \\ \text{interference locations} \end{pmatrix} = \begin{pmatrix} \text{step} \\ \text{in } y \end{pmatrix} = \frac{\lambda/2}{\sin\theta_{\text{final}}} \cong \frac{\lambda/2}{\theta_{\text{final}}} \cong \frac{\frac{1}{2} \times 8\ 68 \times 10^{-12}}{6\ 21 \times 10^{-5}} = 7.00 \times 10^{-8} \quad \text{meter}$$

Because the region of overlap has a full width of $\cong 36 \times 10^{-6}$ meter, there will be roughly 500 interference maxima Note that the interval between adjacent maxima does *not* depend on either b or b_{max} (unlike the situation with ordinary "double slit interference")

Historical note. This problem is based on the now-classic experiment by G Mollenstedt and H Duker, "Observation and Measurement of Biprism Interference with Electron Waves," Zeitschrift fur Physik, **145**, pp. 377-397 (1956)

Theoretical Problem 3: Grading Scheme

Part 1 1 point.

E(r) correct outside of wire: 1 point.

E(r) inside wire: ignore in the grading. (Some students may ignore the interior because there is no field there)

Part 2 5 points, distributed as follows:

θ_{final} independent of b: 1 pt.

$\theta_{\text{final}} \propto \frac{e q_{\text{linear}}}{\varepsilon_0 m v_0^2}$ or $\frac{q_{\text{linear}}}{\varepsilon_0 V_0}$ or equivalent: + 1 pt

Numerical coefficient correct to within a factor of 4 + 2 pts

Numerical coefficient correct to within 20 % + 1 pt

Part 3 1.5 points

Overlap region exists: 0.5 pt

Constant densities of impacts within each region: + 0.25 pt.

Correct ratio of intensities: + 0 25 pt.

Full width of pattern correct, given student's value for θ_{final}: + 0 25 pt.

Width of overlap region correct, given student's value for θ_{final}: + 0.25 pt.

Part 4 2 5 points:

Recognizes that "two wave" interference occurs: 0.5 pt.

Correct de Broglie wavelength : 0.5 pt.

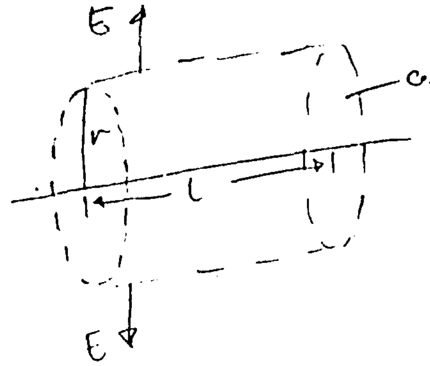
Correct separation of maxima: + 1.5 pts.

[If separation of maxima is wrong by merely a factor of 2, then partial credit: +1 pt]

Maxima in intensity = 4 times single-wave intensity: ignore in grading

1	1
2	.5
3	1.5
4	2.5
Tot	10.[illegible]

1)



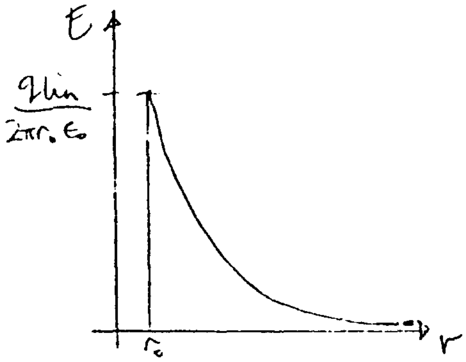
covered surface area $A = 2\pi r l$

Gaussian surface as shown

$$\oint E\cos\theta \, dA = \frac{l q_{lin}}{\epsilon_0}$$

$$\therefore E\, 2\pi r l = \frac{l q_{lin}}{\epsilon_0}$$

$$E = \frac{q_{lin}}{2\pi r \epsilon_0}$$



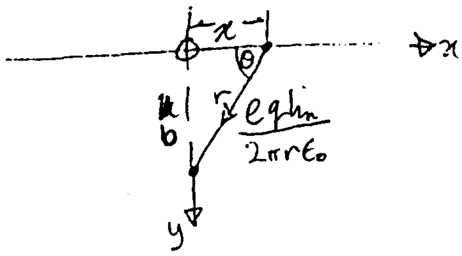
$$E = -\frac{dV}{dr}$$

$$\Rightarrow V = -\int_{\infty}^{r} \frac{q_{lin}}{2\pi\epsilon_0}\frac{1}{r}\, dr$$

2) Force on electron = $\frac{e q_{lin}}{2\pi r \epsilon_0}$ towards wire

For ~~small~~ deflection, $r \simeq b$ while electron is near wire

~~Potential at surface of wire~~



Assume v, velocity of electron $\simeq$ constant while passing wire

then $x = vt$

Component of force $\perp^r$ to motion of electron

$= \dfrac{eq\lambda n}{2\pi r\epsilon_0}\sin\theta$ But $r = x\sec\theta \simeq \sqrt{x^2+b^2}$

$\sin\theta = \dfrac{b}{r} = \dfrac{b}{\sqrt{x^2+b^2}}$

$\therefore$ Component of force $= \dfrac{eq\lambda n}{2\pi\epsilon_0 r}\dfrac{b}{r}$

$= \dfrac{eq\lambda n\, b}{2\pi\epsilon_0(x^2+b^2)} = \dfrac{eq\lambda n\, b}{2\pi\epsilon_0(v^2t^2+b^2)}$

$y = \frac{1}{a}\tan^{-1}\frac{x}{a}$

$\tan y = \frac{x}{a}$

$\sec^2 y\, dy = \frac{1}{a}dx$

$\frac{dy}{dx} = \frac{1}{a\sec^2 y} = \frac{1}{a^2(1+\tan^2 y)} = \frac{1}{a^2(1+\frac{x^2}{a^2})} = \frac{1}{a^2+x^2}$

$\dfrac{dp_y}{dt} = \dfrac{eq\lambda n\, b}{2\pi\epsilon_0(v^2t^2+b^2)}$

p_y = final momentum in y-direction

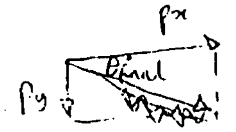
$\displaystyle\int_0^{p_y} dp_y = \frac{eq\lambda n\, b}{2\pi\epsilon_0}\int_{-\infty}^{+\infty}\frac{\frac{1}{v^2}}{\left(\frac{b^2}{v^2}+t^2\right)}dt$

$p_y = \dfrac{eq\lambda n\, b}{2\pi\epsilon_0}\left[\dfrac{1}{v^2}\cdot\dfrac{v}{b}\tan^{-1}\dfrac{vt}{b}\right]_{-\infty}^{+\infty}$

$\dfrac{C\,C\,m^{-1}}{C^2N^{-1}m^{-2}\,ms^{-1}} \Rightarrow Ns\ !$

$= \dfrac{eq\lambda n\, b}{2\pi\epsilon_0}\cdot\dfrac{1}{vb}\left(\dfrac{\pi}{2}-\left(-\dfrac{\pi}{2}\right)\right) = \dfrac{eq\lambda n}{2\epsilon_0 v}$

Small deviation $\rightarrow$ p_x remains unchanged to 1st approximation $\simeq m_e v$



3

Now $\frac{1}{2} m_e v^2 = e V_0$

$$\Rightarrow v = \sqrt{\frac{2eV_0}{m_e}}$$

$$p_x = m_e v = \sqrt{2eV_0 m_e}$$

$$p_y = \frac{e q l_{in}}{2\epsilon_0 v} = \frac{e q l_{in}}{2\epsilon_0}\sqrt{\frac{m_e}{2eV_0}}$$

$$\tan(\theta_{final}) = \frac{p_y}{p_x} = \frac{e q l_{in}}{2\epsilon_0}\sqrt{\frac{m_e}{2eV_0 \cdot 2eV_0 m_e}}$$

$$= \frac{e q l_{in}}{2\epsilon_0 2eV_0} = \frac{q l_{in}}{4\epsilon_0 V_0}$$

$$\simeq 6.215 \times 10^{-5}$$

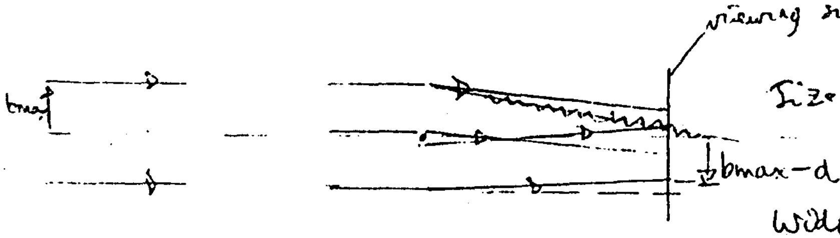
$$\Rightarrow \theta_{final} \simeq 6.215 \times 10^{-5} \text{ rad}$$

$$\simeq 6.21 \times 10^{-5} \text{ rad}$$

3. Linear deflection of electron from original path

$$= \theta_{final} \times L$$

$$d = 1.86 \times 10^{-5} \text{ m} \quad \text{towards wire}$$



Size of overlap

$$= 2d - 2r_0$$

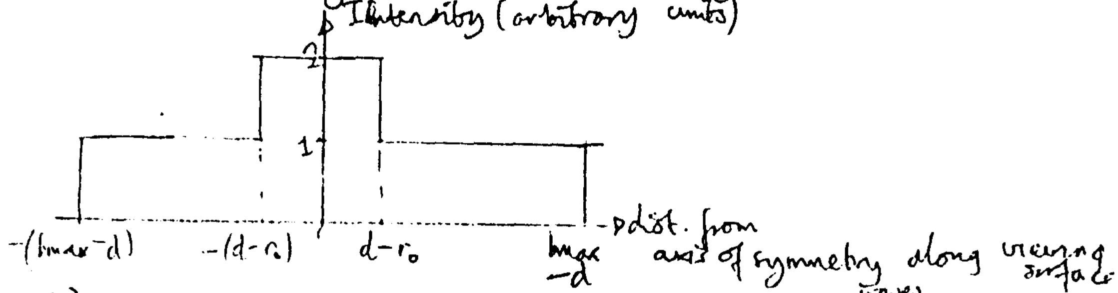
$$= 3.53 \times 10^{-5} \text{ m}$$

Width of whole pattern $= 2b_{max} - 2d$

$$= 1.63 \times 10^{-4} \text{ m}$$

3

Hence intensity distribution is given by $\Delta x = \frac{\lambda d}{s}$



4) Quantum theory predicts interference of electron waves in the area of overlap

Wire in effect ~~...~~ produces two sources of electrons each at ~~θ~~ $\theta_{final} \times l$ from axis of symmetry

[l = distance from virtual sources to viewing surface]

So double-slit diffraction pattern is produced on screen

1st Maximum intensity is on axis of symmetry

Distance Δx between adjacent maxima given by

$$\Delta x = \frac{\lambda l}{2\theta_{final} \times l} \qquad \left[\Delta x = \frac{\lambda d}{s}\right.$$

$$= \frac{\lambda}{2\theta_{final}}$$

Now $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2eV_0 m_e}}$

$$\therefore \Delta x = \frac{h}{\sqrt{2eV_0 m_e} \cdot 2\theta_{final}}$$

$$= 6.989 \times 10^{-8}\ \text{m}$$

No. of fringes in area of overlap $= \frac{2d - 2r_0}{\Delta x}$

$\simeq 505$.

COUNTRY : ________________

XXIV INTERNATIONAL PHYSICS OLYMPIAD

WILLIAMSBURG, VIRGINIA, U.S.A.

PRACTICAL COMPETITION

Experiment No. 1

July 14, 1993

Time available: 2.5 hours

READ THIS FIRST!

INSTRUCTIONS:

1. Use only the pen provided.
2. Use only the marked side of the paper.
3. Write at the top of each and every page:
   - The number of the problem
   - The number of the page of your report
   - The total number of pages in your report.

   Example (for Problem 1): 1 1/4; 1 2/4; 1 3/4; 1 4/4.

Experimental Problem 1

THE HEAT OF VAPORIZATION OF NITROGEN

The object of this experiment is to measure the heat of vaporization per unit mass (L) of nitrogen using two different methods In Method #1, you will add a piece of aluminum to the sample of liquid nitrogen and measure how much liquid nitrogen evaporates as the aluminum cools. In Method #2, you will add energy in the form of heat at a known rate to the sample of liquid nitrogen and measure the rate at which the liquid nitrogen vaporizes

The liquid nitrogen is supplied to you in the "reservoir" container Some of it can be poured into the "sample" container, which can be placed on the mass balance The reading of the mass balance will decrease as liquid nitrogen vaporizes This occurs (1) because the container is not a perfect insulator, (2) because energy is being added to the liquid nitrogen in the form of heat when the aluminum cools (in Method #1), and (3) because energy is being added to the liquid nitrogen in the form of heat when current passes through a resistor placed in the liquid nitrogen (in Method #2) A multimeter, which can be used to measure voltage (V), current (I), and resistance (R), as well as a stopwatch are supplied Instructions for using the multimeter and stopwatch are attached

Warnings

(1) Liquid nitrogen is very cold, so do not let it, or any object which has been cooled by it, touch you or your clothing in any way.

(2) Do not drop anything in the liquid nitrogen, and wear safety goggles at all times.

(3) Place the piece of aluminum in the liquid nitrogen slowly, as it will cause the liquid nitrogen to boil rapidly until equilibrium is reached. A piece of string is supplied for this purpose.

(4) The resistor can get very hot if it is not immersed in the liquid nitrogen. Pass current through the resistor only when it is in the container and completely immersed in liquid nitrogen.

Method #1

The specific heat of aluminum (c) varies significantly between room temperature and the temperature at which liquid nitrogen vaporizes under atmospheric pressure (77 K) A graph showing the variation of c with temperature (T) is attached Conduct an experiment to measure how much liquid nitrogen vaporizes when the aluminum block is cooled Use this determination and the specific heat graph to determine the heat of vaporization per unit mass of nitrogen You may assume that room temperature is 21±2°C Be sure to provide a quantitative estimate of the accuracy of your heat of vaporization value

Method #2

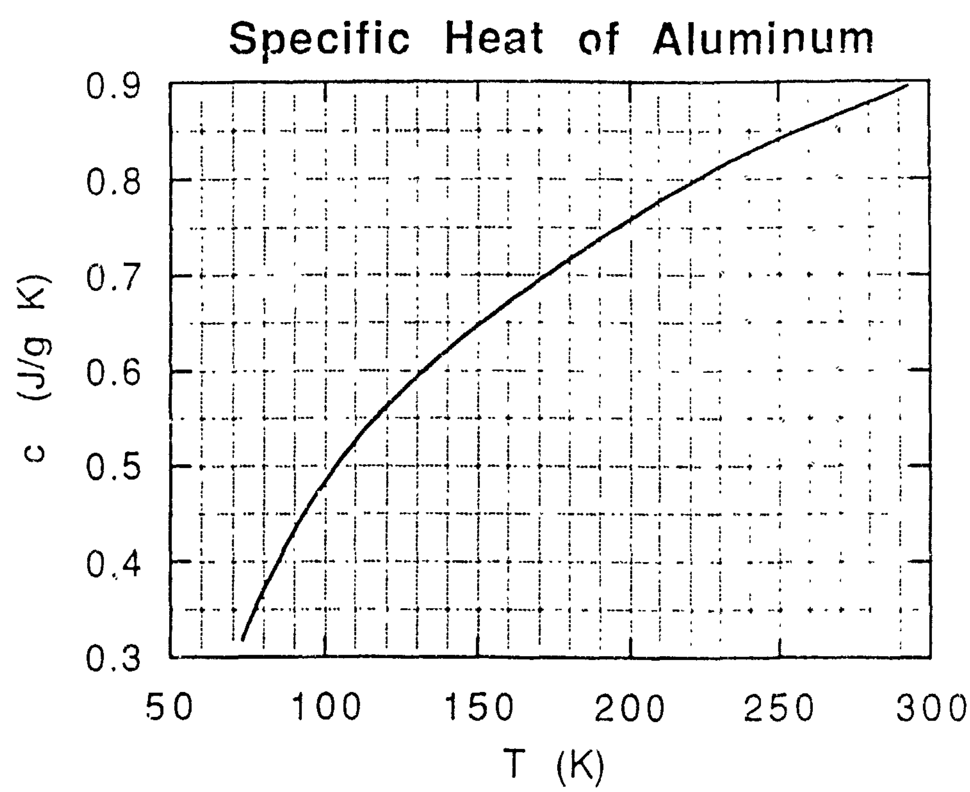
Conduct an experiment to measure the rate at which liquid nitrogen vaporizes when current is passed through the resistor placed in the liquid nitrogen A direct current power supply is provided, <u>use it only with the dial in the "8" position and do not disconnect the</u>

capacitor installed across its terminals Use this result to determine the heat of vaporization per unit mass of nitrogen Be sure to provide a quantitative estimate of the accuracy of your result

Notes:

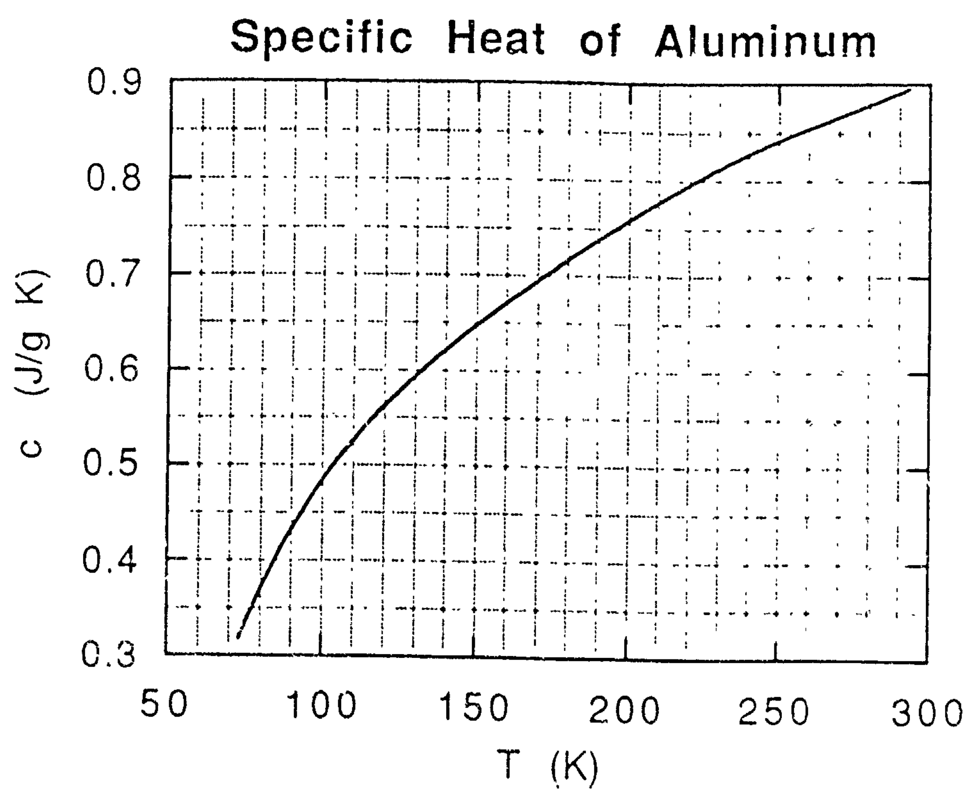
(1) Please include sketches, schematic diagrams, properly labelled tables, numbers with the proper units, etc. so the graders can determine exactly what you did.

(2) Ask for assistance if any piece of equipment is not working properly.

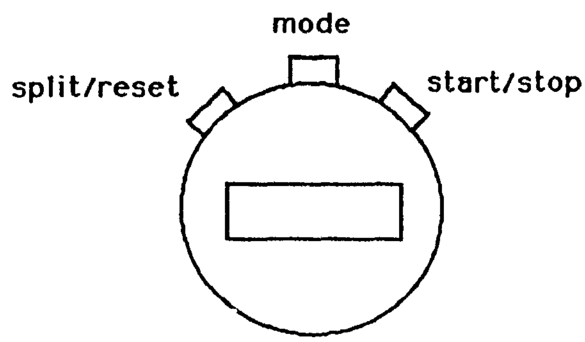


capacitor installed across its terminals. Use this result to determine the heat of vaporization per unit mass of nitrogen Be sure to provide a quantitative estimate of the accuracy of your result.

Notes:
(1) Please include sketches, schematic diagrams, properly labelled tables, numbers with the proper units, etc. so the graders can determine exactly what you did.
(2) Ask for assistance if any piece of equipment is not working properly.



Digital Stopwatch



To Perform Timing Operations

1. Press "Mode" until 0 00 00 appears
   (You may have to press "Mode" several times to get the 0 00 00 to appear)

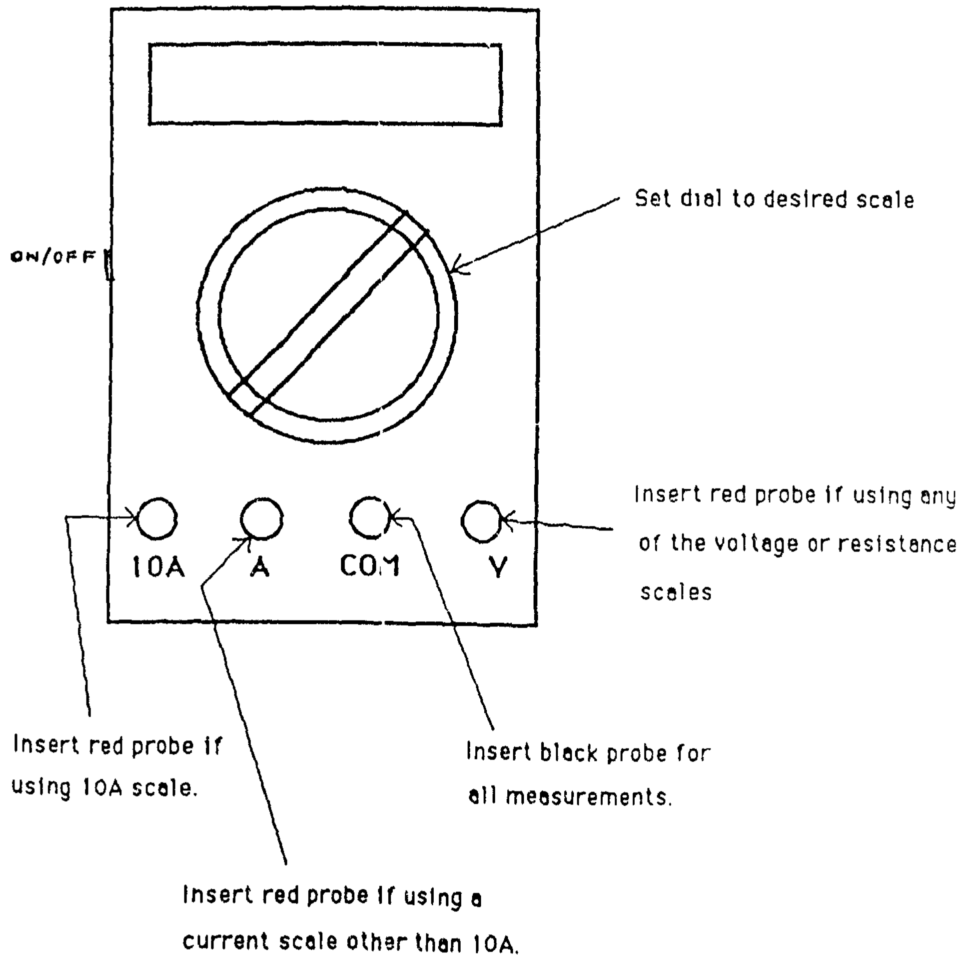
To Time a Single Interval

1. Press "Start/Stop" to start stopwatch.
2. Press "Start/Stop" to stop stopwatch.
3. Press "Split/Reset" to reset stopwatch to zero

To Time Multiple Events Without Stopping the Stopwatch

1. Press "Start/Stop" to start stopwatch.
2. Press "Split/Reset" to stop the display while stopwatch keeps running
3. Press "Split/Reset" to reset display to actual time.
4. Press "Start/Stop" to stop stopwatch after last event.
5. Press "Split/Reset" to reset stopwatch to zero.

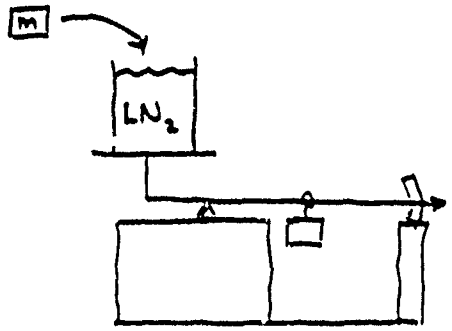
Multimeter



ON/OFF
10A
A
COM
V
Set dial to desired scale
Insert red probe if using any of the voltage or resistance scales
Insert red probe if using 10A scale.
Insert black probe for all measurements.
Insert red probe if using a current scale other than 10A.

Experimental Problem 1 -- Solutions

Method #1

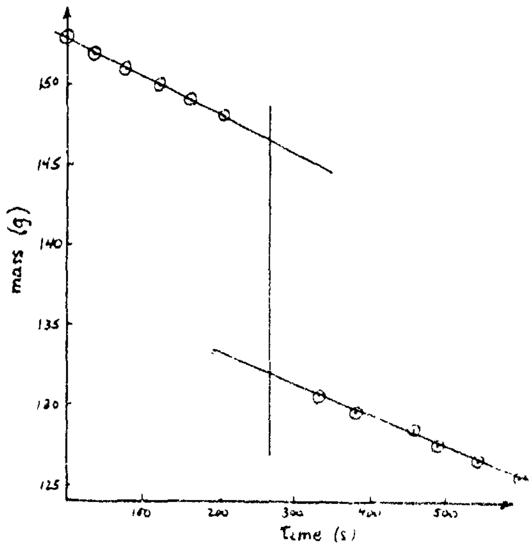


$Q = mc\Delta T = m\int c\,dT$

$Q = L\,\Delta M_{LN_2}$

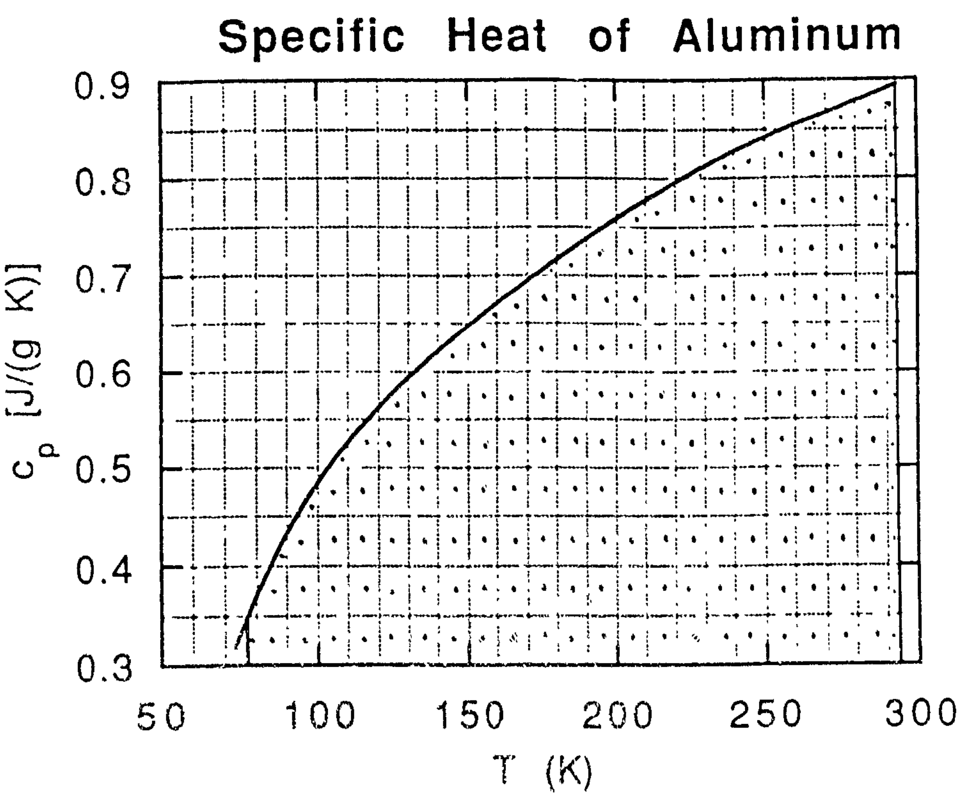
$m = 19.4 \pm 0.1$ g

	total mass	clock time	time
	153 g	0:00 0	0
	152	0:36.8	36.8
	151	1:19.1	79.1
	150	2:00.7	120 7
	149	2:40.5	160.5
	148	3.23.1	203.1
Add Al mass			
	150 (130.6)	5:31.8	331 8
	149 (129 6)	6:21.6	381.6
	148 (128 6)	7:17.3	457.3
	147 (127.6)	8:08.6	488 6
	146 (126.6)	9:00.9	540 9
	145 (125.6)	9:54.6	594.6



$\Delta M_{LN_2} = 146.5 - 132.0$
$= 14.5 \pm 0.3$ g

Method #1 (cont'd)



$$\int_{77}^{293} c\,dT \approx (0.3)(293-77) + (173)(0.5)$$

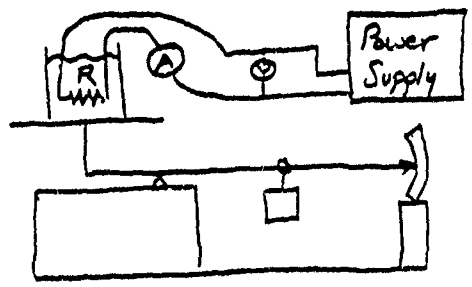
$$= 64.8 + 86.5 = 151 \pm 2 \text{ J/g}$$

$$Q = \int m\,c\,dT = (19.4 \pm 0.1 \text{ g})(151 \pm 2 \text{ J/g})$$

$$= 2930 \pm 42 \text{ J.}$$

$$L = \frac{Q}{\Delta M_{LN2}} = \frac{2930 \pm 42 \text{ J}}{14.5 \pm 0.3 \text{ g}} = 202 \pm 5 \text{ J/g}$$

Method #2



$P = IV = V^2/R = I^2R$

$P = \Delta Q/\Delta t$

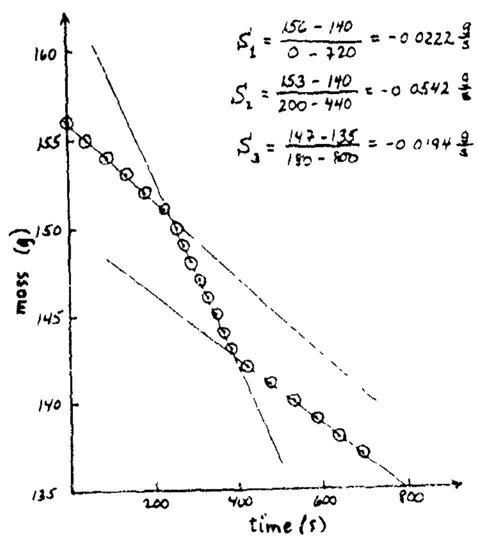
$Q = M_{LN_2}L$

$R = 23.0\ \Omega$ (in LN_2)

$V = 12.7$ V

$I = 0.56$ A

	total mass	clock time	time
	156 g	0:00.0	0 s
	155	0:45.2	45.2
	154	1·31.4	91.4
$P = 0$	153	2:16 2	136 2
	152	2:60.0	180.0
	151	3:47.2	227.2
	150	4:13.6	253.6
	149	4:32 1	272.1
	148	4·50.1	290.1
$P \neq 0$	147	5.08 9	308.9
	146	5:27.2	327.2
	145	5 45.7	345.7
	144	6·04.1	364.1
	143	6:21 9	381.9
	142	7.02 3	422 3
	141	7·58 4	478 4
$P = 0$	140	8·51 2	531 2
	139	9:43 7	583.7
	138	10:34 6	634 6
	137	11:30 7	690 7



$S_{P\neq 0} = -0\ 054 \pm 0.001$ g/s

$\langle S_{P=0}\rangle = -0.020 \pm 0\ 001$ g/s

$$\text{Power} = P = \left|\frac{Q}{\Delta t}\right| = L\left|\frac{\Delta M_{LN2}}{\Delta t}\right|$$

$$\left.\begin{aligned} P &= IV = 7.11\ \text{W} \\ P &= I^2R = 7.21\ \text{W} \\ P &= V^2/R = 7.01\ \text{W} \end{aligned}\right\} P = 7.1 \pm 0\ 1\ \text{W}$$

$$|\Delta M_{LN_2}/\Delta t| = 0\ 054 - 0.020 = 0.034 \pm 0\ 0014\ \text{J/s}$$

$$L = \frac{P}{\Delta M_{LN2}/\Delta t} = \frac{7\ 1 \pm 0.1}{0.034 \pm 0\ 0014} = 209 \pm 9\ \text{J/g}$$

Experimental Problem 1: Grading Scheme

Method No. 1 (5 points maximum)

1) 0.5 Uses $Q = mc\Delta T$ or $Q = m \int c\, dT$

2) 0.5. Uses $Q = L\Delta M_{LN_2}$

3) 0.5 Measures mass of aluminum correctly

4) 0.5 Measures ΔM_{LN_2} in some way

5) 0.5 Takes into account "thermal leakage" in some way and corrects for aluminum added to container

6) 0.5 Takes into account "thermal leakage" not being constant in time

7) 0.5 Uses reasonable values for c and ΔT or does $\int c\, dT$ integral in a reasonable way

8) 0.5 No mistakes made in computing L

9) 0.5 Error estimate is reasonable for methods used

10) 0.5 Value for L is within bounds set by grading team using good procedures

Method No. 2 (5 points maximum)

1) 0.5 Uses $P = \Delta Q/\Delta t$

2) 0.5 Uses $P = IV = I^2R = V^2/R$

3) 0.5 Uses $Q = LM_{LN_2}$

4) 0.5 Measures two parameters (to get P) correctly

5) 0.5 Measures M_{LN_2} in some way

6) 0.5 Takes into account "thermal leakage" in some way

7) 0.5 Takes into account "thermal leakage" not being constant in time

8) 0.5 No mistakes made in computing L

9) 0.5 Error estimate is reasonable for methods used

10) 0.5 Value for L is within bounds set by grading team using good procedures

$T_k \approx 21 \pm 2\ ^\circ C = 294 \pm 2\ K$

#1, Az Al-darab 77 K-re hűl le, hiszen majd folyékony N_2 is az edényben.
Először a N ~~[illegible]~~ tömeg-változását kell lemérni az idő függvényében az Al-darab nélkül, hogy ezt aztán korrekcióba vehessük.
Tehát „üresen” a N: $\varepsilon = \frac{dm}{dt}$. ε-t kell meghatároznunk.
Az Al-darab a folyadéknak $E = \int_{77K}^{294K} CMdT$ energiát ad le (ezt a C-T grafikonból numerikus integrálással kaphatjuk),
Tehát a folyadék tömegcsökkenése:

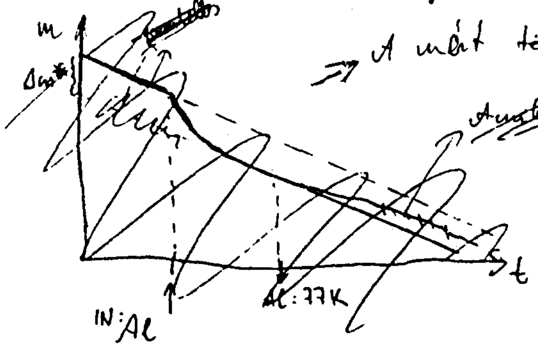
$$L\Delta m = E = \int_{77}^{294} cMdT$$

$$\Delta m = \frac{M}{L}\int_{77}^{294} cdT$$

A mért tömegváltozás azonban több ennél:

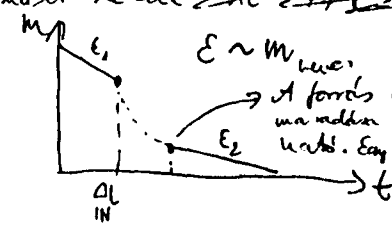
$\Delta m^* = \Delta m + \varepsilon t$, a t a mérés ideje.

M az Al-darab tömege. Mérleggel lemérve: $M = 19{,}6\,g \pm 0{,}1\,g$



⇒ A mért tömegváltozás meghatározása.

~~Amikor $\frac{dm}{dt}$ [illegible] E [illegible]~~
~~[illegible] Al 77 K-re.~~



$\varepsilon \sim m_{N_2}$

A forrás abbamaradása jól látható. Egy szakaszt ezután kell mérnünk.

Az m – t táblázat:

AL IN ↓ $-19{,}6\,g \equiv M$:

						152,4	151,4	150,4	149,4	148,4	147,4
m (g)	180	178	176	174	172	172	171	170	169	168	167 } ±0,1 g
t (s)	0	57,6	1:56,2 = 116,2	2:55,8 175,8	3:54,6 234,6	6:20,5 380,5	6:57,1 417,1	7:33,7 453,7	8:11,4 491,4	8:48,1 528,1	9:24,5 564,5 } ±0,2 s

Érdemes pl. 2g-onként mérni az időt, mert a tömeg állítható a mérlegen. Így azt kell figyelni, hogy mikor éri el az állítás után a mérleg mutatója a "0" helyzetet.
Az Al behelyezése után csak a heves forrás után mértem.
A diagramról:

$$\varepsilon_1 = -0{,}0337\,\frac{g}{s} \pm 0{,}13\% \qquad \varepsilon_2 = -0{,}0275\,\frac{g}{s} \pm 0{,}13\%$$

$m: 0{,}1g/170g = 0{,}06\%$ hiba
$t: 0{,}2s/300s \approx 0{,}07\%$ hiba
$\Sigma \approx 0{,}13\%$ hiba

Tapasztalat: $\dfrac{\varepsilon_1}{\varepsilon_2} \cong \dfrac{m_1}{m_2} = \dfrac{180g}{147g}$!!!

Tehát a párolgás a tömeg függvénye: $\boxed{\text{exponenciális}}$an változik!

$$\varepsilon = \frac{-0{,}0337\,\frac{g}{s}}{180g} \cdot m = -0{,}1872\,\frac{mg}{s} \cdot m$$

$\pm 0{,}13\%$

$$\frac{dm}{dt} = -0{,}1872\,\frac{mg}{s} \cdot m$$

$$\cancel{\frac{dm}{m} = 0{,}1872\,dt}$$

$$m = m_0 e^{-\lambda t} \qquad \lambda = 0{,}1872\,\frac{mg}{s}$$

$$\frac{dm}{dt} = m_0 e^{-\lambda t} \cdot (-\lambda) = m \cdot -\lambda$$

Al nélkül:

$$m = m_0 e^{-1{,}872 \cdot 10^{-4} t} \quad (SI)$$

univerzális állandó!!! $\pm 0{,}13\%$
(erre a pohárra)

Country: Hungary
Student Number: 5
Page 3 of 6 Pages

1.

A tömegváltozás kiszámolása:

A két szélső mérési pont között:

$0\,s \qquad 564{,}5\,s$ > 564,5 s alatt a nitrogén tömegváltozása

$180\,g \qquad 147{,}4\,g$ Al nélkül: $180\,g - 180\,g \cdot e^{-1{,}872 \cdot 10^{-4} \cdot 564{,}5} =$ (± 1,3%)

$= 18{,}1\,g \pm 0{,}1\,g$ (± 0,13%)

A teljes mért tömegváltozás: $180\,g - 147{,}4\,g = 32{,}6\,g \pm 0{,}1\,g$

A Δm értéke: $32{,}6\,g - 18{,}1\,g = \underline{14{,}5 \pm 0{,}25\,g}$

Az Al 293 K energiát párologtatott el.

$\int\limits_{77K} c\,dT$ kiszámolása: (trapézformulával):

$3 \cdot 0{,}35 + 10(0{,}41 + 0{,}47 + 0{,}51 + 0{,}54 + 0{,}58 + 0{,}62 + 0{,}635 + 0{,}66 +$
$+ 0{,}68 + 0{,}71 + 0{,}73 + 0{,}75 + 0{,}77 + 0{,}785 + 0{,}81 + 0{,}82 + 0{,}835 + 0{,}85 +$
$+ 0{,}865 + 0{,}875 + 0{,}88) + 4 \cdot 0{,}9 = 152{,}5 \pm 2\%$ $\frac{J}{g}$

kalor. pontosság: $0{,}015 \frac{J}{gK}$

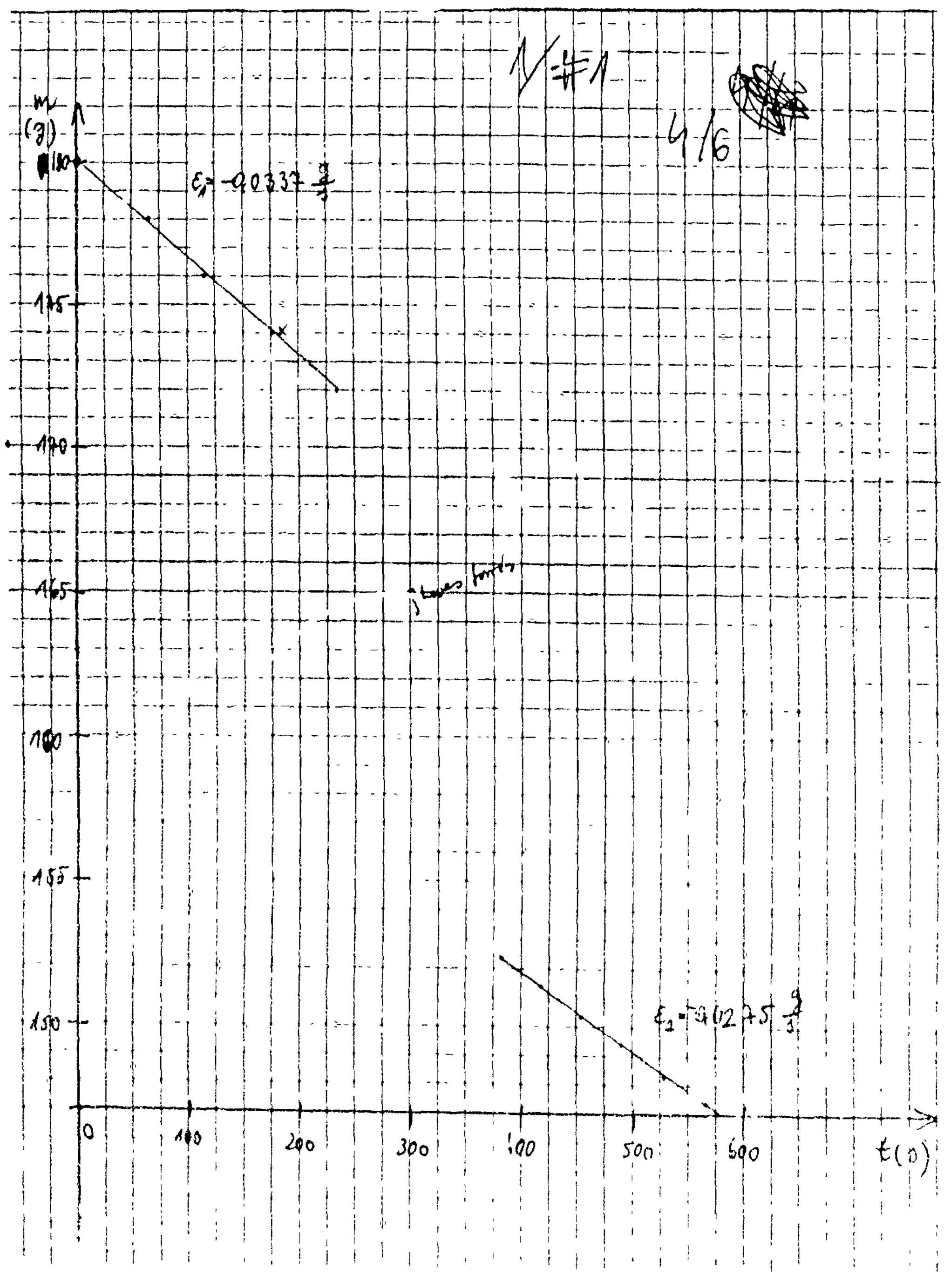
20 kalor. hibája: $\dfrac{\frac{0{,}015 \frac{J}{gK}}{\sqrt{20}}}{0{,}6 \frac{J}{gK}} \approx 2\%$

Végül az Al forráshője:

$L \cdot 14{,}5\,g = 152{,}5 \frac{J}{g} \cdot 19{,}6\,g$

(1,5%) (2%) (0,5%)

$L = 206{,}1 \frac{J}{g} \pm 4\% = \boxed{206{,}1 \pm 8 \frac{J}{g}}$



m (g)
180
175
170
165
160
155
150
0
100
200
300
400
500
600
t (s)

#2) $R = 22,1\ \Omega$ $\pm 0,45\%$ A lehűtött (77K) ellenálláson.

180g	m(g)	190g	188g	186g	182	180	~~178~~	176	174	172	168	160
	t(s)	0	26,5	53,3	108,6	137,[illegible]	[illegible]	193,8	222,1	251,6	310	430,1

$\pm 0,1g$

$\pm 0,2s$

136

~~I = 0,2275 A~~

$I = 0,575 A \pm 0,001 A$

Az előbb is érvényes párolgási állandó itt is fennáll: fűtés nélkül: $m(t) = m_0 e^{-1,872\cdot 10^{-4} t}$, ahol $\lambda = -1,872\cdot 10^{-4}\ \frac{1}{s} \pm 0,13\%$

Az ellenálláson az I áramerősség végig állandó volt:

$I = 0,575 \pm 10^{-3} A$ (0,2%)

Az ellenállás is konstans volt a N-ben: $R = 22,1 \pm 0,1\ \Omega$ (0,5%)

430,1 s alatt az ellenálláson termelt hő:

$$Q = I^2 R t = 0,575^2 \cdot 22,1 \cdot 430,1\ J = 3142,7\ J$$

($\pm$ 0,2·2 + 0,5% = 0,9%)

Az elpárolgott N tömege: $190g - 160g = 30g$ ($\pm 0,1g$) (0,3%)

Ebből elpárolgott volna a rossz hőszigetelés miatt:

$$190g - 190g \cdot e^{-1,872\cdot 10^{-4}\cdot 430,1} = 14,7g \quad (\pm 1,3\%)$$

Tehát a Q hő hatására elforrt nitrogén tömege:

$$30g - 14,7g = \underline{15,3g} \quad (\pm 1,6\%)$$

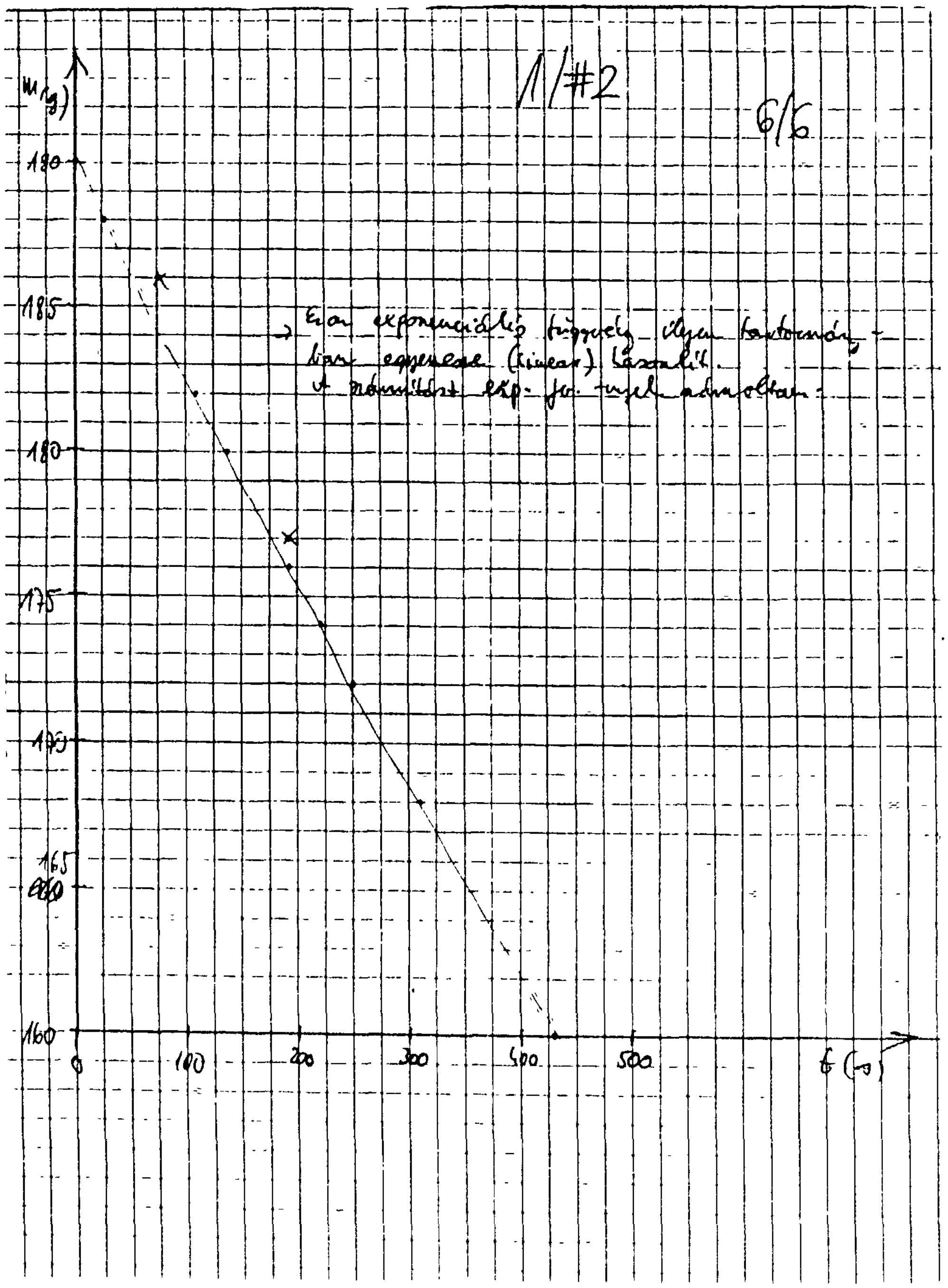
A nitrogén forráshője:

$$L \cdot 15,3g = Q = 3142,7\ J \ (0,9\%)$$

(1,6%) $L = 205,4\ \frac{J}{g}$ ($\pm$ 2,5%)

$$\boxed{L = 205,4 \pm 5,1\ \frac{J}{g}}$$

Látható, hogy a #1 és #2 eredmények hibán belül azonosak.


1/#2
6/6
m (g)
180
175
160
0
100
200
300
400
500
t (s)

COUNTRY: ______________

XXIV INTERNATIONAL PHYSICS OLYMPIAD
WILLIAMSBURG, VIRGINIA, U.S.A.

PRACTICAL COMPETITION

Experiment No. 2

July 14, 1993

Time available: 2.5 hours

READ THIS FIRST!

INSTRUCTIONS:

1. Use only the pen provided, and only the equipment supplied.
2. Use only the marked side of the paper.
3. Write at the top of each page:
   - The number of the problem
   - The number of the page of your report
   - The total number of pages in your report.

   Example (for problem 1): 1 1/4; 1 2/4; 1 3/4; 1 4/4

Experimental Problem 2

MAGNETIC MOMENTS AND FIELDS

This experiment has two parts:

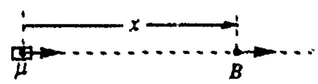
Part 1: To determine the absolute magnitude μ_X of the magnetic moment of a small cylindrical permanent magnet, contained in the envelope marked "X" (A similar magnet, also needed for the experiment, is contained in the envelope marked "A".)

Part 2: To investigate the magnetic field of a given axially symmetric distribution of magnets, contained in the envelope marked "B".

In your experiments, you should make use of the following facts:

(1) The magnetic field B produced by a dipole magnet at a point along its axis at distance x from its center is parallel to that axis and of strength given by:

$$B(x) = \frac{2\mu K}{x^3},$$



where B is in Tesla [= N/(A m)], $K = 10^{-7}$ Tesla m/A, x is in m, and μ is in A m^2.

(2) The period of small torsional (angular) oscillations of a horizontal freely suspended magnet, such as a compass needle in the Earth's magnetic field, is given by:

$$T = 2\pi\sqrt{\frac{I}{\mu B_h}},$$

where B_h is the horizontal component of the net field at the magnet, and I is the moment of inertia of the magnet about a vertical axis through its center.

Apparatus

The apparatus is illustrated in the diagrams at the end. A thin thread is suspended from the upper of two shelves on a wooden stand. A magnet ("X" or "A") can be attached to the bottom end of the thread. A copper plate can be placed on the lower shelf, just below the suspended magnet, to damp out its motion if desired. Two auxiliary wooden stands are provided One of these serves as a holder for either "A" or "X" in Part 1; the other holds the magnet system B (used in Part 2). Distances between a suspended magnet and a magnet mounted in one of the auxiliary stands can be measured with a ruler mounted on that stand.

Warning: These magnets are extremely strong. Hold onto them tightly and be careful not to let them be pulled out of your fingers.

PART 1

The magnetic moment to be determined (μ_X) is that of the pair of magnets in envelope X, labelled at the ends with a letter-number combination Always keep this pair together The moment of inertia of this pair has been calculated and written on envelope X Envelope A contains another pair of magnets with north and south poles marked respectively with black and red spots This pair is similar

to the pair from envelope X, though its magnetic moment (μ_A) cannot be assumed equal to μ_X. A given pair of magnets can be "split" and placed around the bronze disk attached to the thread, forming a "compass" whose torsional oscillation period may be measured. (The value I_X given on envelope X includes the effects of the bronze disk.)

One magnet-pair, centered in the hole in the wooden holder, can be used to influence the "compass" pair, possibly affecting its period and its angular equilibrium position. The angular position is best studied by placing the copper plate a few millimeters below the "compass" so as to provide electromagnetic damping. **Please do not mark or write on the copper plate.**

You will need to use more than one arrangement of the magnets. **Draw clearly labelled diagrams showing each experimental arrangement used. Also, write equations to show how you will combine your different observations to obtain the value of μ_X.**

Keep all magnets in the same horizontal plane. Note for the main stand that the top knob can be rotated, and the thread length adjusted. The position of each shelf can also be adjusted.

Practical Details (IMPORTANT!)

1) COMPASS ASSEMBLY AND USE: Hold one magnet from a given pair between the thumb and forefinger of one hand. Center the bronze disk over one end. Then, carefully, and without pulling on the thread, slowly bring in the second magnet. This forms the compass pair ("X" or "A"). Also, avoid pulling on the thread in taking the compass apart.
   Warning: Rapid snapping of magnets or magnet pairs together can break the thread or chip the magnets. The tiny loop can be threaded again if thread breakage occurs. (Consult the organizers if necessary.)

2) Study the torsional mode of oscillation. To prevent excitation of the "pendulum" mode, a small assembly made of copper wire is mounted on the lower shelf of the main stand. Rotate this assembly so that the horizontal piece is up against the thread at a point about 2 mm above where the thread is tied. With a slight additional rotation in the same direction, move the wire a few mm further.
   Warning: If this is not done, the two modes can "couple," causing a periodic variation in the amplitude of the torsional oscillations, and affecting their period.
   Use the nail (see diagrams at end) to start the torsional oscillations in a controlled way.

3) Keep magnetic or magnetizable objects stationary, and as far as possible from the experimental area. Consider such items as the nail, wrist watches, pens, etc. The table has some steel support parts; if you want to change the position of the apparatus, consider this fact.

Suggestions

(i) The torsion constant of the thread is quite small. It turns out that you can neglect its effect in the analysis provided the thread is reasonably long, e.g. around 15 cm.

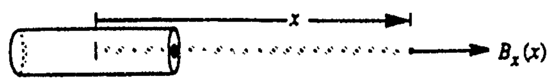
(ii) You may notice that a given magnet pair does not hang horizontally. This is because of the vertical component of the Earth's field. The effect of this on the analysis is small and should be neglected. In other words, simply pretend that the magnet is horizontal.

(iii) We suggest that you postpone the error analysis for Part 1 until after you have made the measurements needed for Part 2.

(iv) **You should not make any assumptions about the magnitude of the Earth's field.**

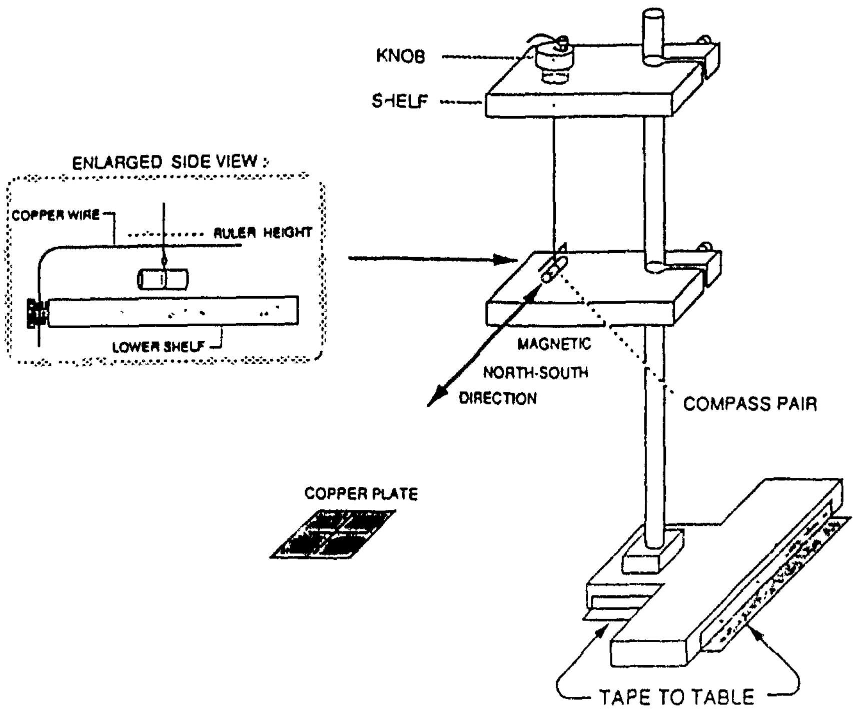
PART 2

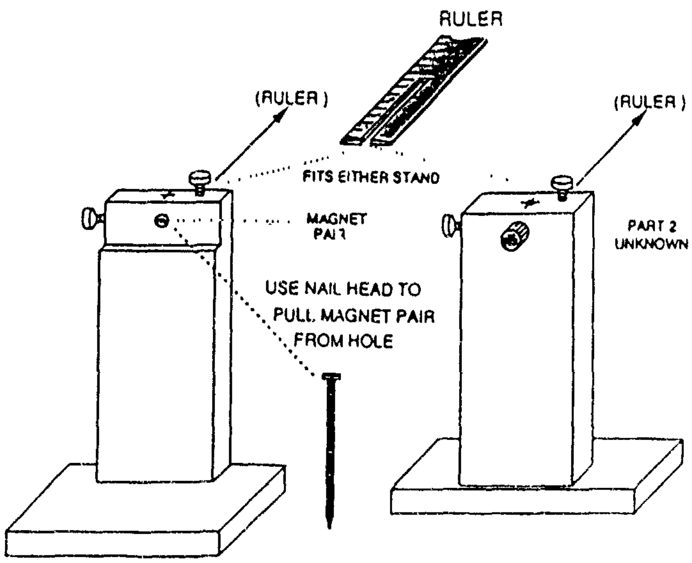
The aluminum tube (in envelope B) contains an axially symmetrical distribution of magnets. The magnetic field along the x axis, B_x, of this assembly varies as a function of distance x measured from the center of the tube according to the relation $B_x(x) = Cx^p$. Determine the exponent p, with its approximate error. As sketched below, you should study the field on the side in the direction of the end marked with a black spot.



WRITE YOUR SET-UP NUMBER ON YOUR REPORT. THIS IS THE LETTER-NUMBER COMBINATION PRINTED ON THE EQUIPMENT BOX AND ALSO ON THE MAGNET ENVELOPES LIKE THIS:

$\boxed{}$


KNOB
SHELF
ENLARGED SIDE VIEW :
COPPER WIRE
RULER HEIGHT
LOWER SHELF
MAGNETIC
NORTH-SOUTH
DIRECTION
COMPASS PAIR
COPPER PLATE
TAPE TO TABLE


RULER
(RULER)
(RULER)
FITS EITHER STAND
MAGNET
PAIR
PART 2
UNKNOWN
USE NAIL HEAD TO
PULL MAGNET PAIR
FROM HOLE

Experimental Problem 2 -- Solutions

PART 1 : DETERMINATION OF μ_X

Basic Insight :

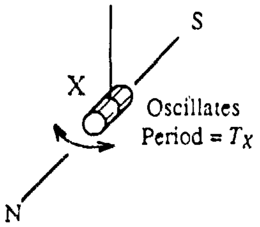
The idea which enables one to "see into" the problem is contained in the following remark: The oscillation period of a given suspended magnet depends on the product of its moment and the (horizontal component of) the Earth's field, while the extent to which that magnet can influence the direction of another magnet used as a compass depends on the ratio of those two quantities.

It follows that by making measurements of both types, both the unknown moment and the horizontal component of the Earth's field can be determined. We suspect that this idea goes historically back to Gauss.

First Solution : The "Turn-Around Method"

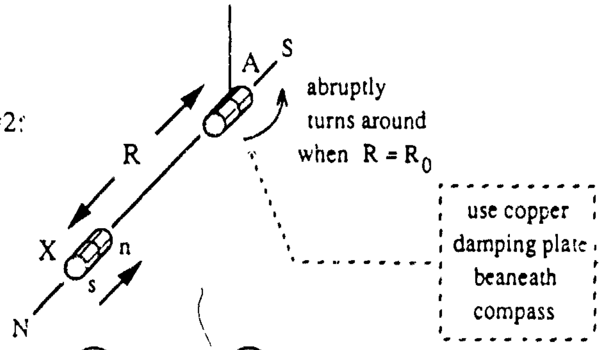
Experimental Arrangement — Equation

#1:



$$\mu_X B_h = I_X (2\pi/T_X)^2 \qquad (1)$$

#2:



$$\mu_X \frac{2K}{R_0^3} = B_h \qquad (2)$$

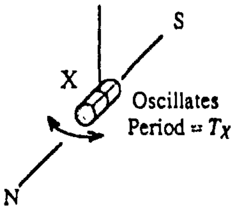
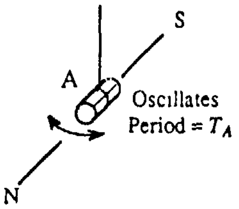
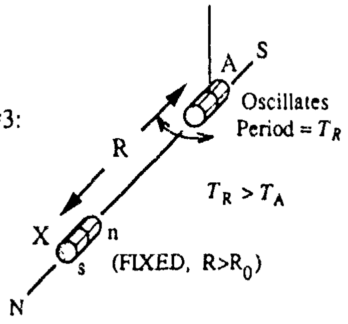
note that the μ and I values of the compass magnet do not matter

Combining (1) and (2) one easily finds:

$$\boxed{\mu_X = \frac{R_0^{3/2}}{(2K)^{1/2}} \frac{2\pi}{T_X} (I_X)^{1/2}}$$

Second Solution : Dynamic Method with 3 Unknowns

The experience from our tests was that the "Turn-Around" method did not occur naturally to most students. They were much more comfortable with the idea of using one magnet to influence the period of another. Since the magnetic moments are not necessarily equal, it is clear that two measurements will no longer suffice. Our guess is that the following 3-measurement scheme will be the most common student choice.

Experimental Arrangement		Equation	
#1:		$\mu_X B_h = I_X (2\pi/T_X)^2$	1
#2:		$\mu_A B_h = I_A (2\pi/T_A)^2$	2
#3:		$\mu_A \left[B_h - \mu_X \frac{2K}{R^3}\right] = I_A (2\pi/T_R)^2$	3

Note that the X magnet (positioned at a distance R which is somewhat larger than the turn-around distance R_0) is being used here to slow the oscillations of the A magnet on the compass.

One worries at first that there are actually 4 unknowns, since the inertial moment of A need not equal that of X Inspection of equations 2 and 3 shows, however, that the ratio μ_X/B_h can be expresed

in terms of experimentally known quantities. Since (1) gives the product $\mu_X B_h$, the calculational strategy is clear. One easily finds:

$$\boxed{\mu_X = \frac{R^{3/2}}{(2K)^{1/2}} \frac{2\pi}{T_X} (I_X)^{1/2} \left[1 - (T_A/T_R)^2\right]^{1/2}} \qquad (4)$$

Alternatively, by reversing its poles, one can use the X magnet to speed-up the oscillations of the A magnet. Then, of course we have $T_R < T_A$. In this case (which is formally equivalent to the first case, with a reversal of the sign of K), one finds:

$$\boxed{\mu_X = \frac{R^{3/2}}{(2K)^{1/2}} \frac{2\pi}{T_X} (I_X)^{1/2} \left[(T_A/T_R)^2 - 1\right]^{1/2}} \qquad (4')$$

SAMPLE EXPERIMENT

The Dynamic Method just outlined was used (in the case where the X magnet was used to slow down the oscillations of the A magnet in Arrangement #3). In all cases 20 oscillations were timed. The distance R was (17.0±0.1) cm. The X moment of inertia was $I_X = (4.95 \pm 0.1) \times 10^{-8}$ kg m^2. Using the notation given previously, the data were as follows:

Measurements (in seconds) of $20T_X$: 10.83, 10.99, 10.91, 10.94. [Arrangement #1]

Measurements (in seconds) of $20T_A$: 10.95, 11.10, 11.01, 10.92. [Arrangement #2]

Measurements (in seconds) of $20T_R$: 21.70, 21.65, 21.78, 21.59. [Arrangement #3]

Using a pocket calculator (HP32S) to obtain the averages and statistical errors gives:

$T_X = (0.546 \pm .003)$ sec

$T_A = (0.550 \pm .004)$ sec

$T_R = (1.084 \pm .004)$ sec

The "statistical errors" here are naively based on what the calculator gave for the estimated standard deviation around the sample mean. More carefully, one should divide this by the square root of the number of observations to give the estimated standard error of the sample mean. [Still more carefully, for such a small sample, one should apply the appropriate statistical correction factor]. For simplicity

we will use the naively calculated results. This will suffice for our purposes.

Write (4) as $\mu_X = G\,F$, where

$$G = \frac{R^{3/2}}{(2K)^{1/2}}\,\frac{2\pi}{T_X}\,(I_X)^{1/2} \qquad \text{and} \qquad F = \left[1 - (T_A/T_R)^2\right]^{1/2}$$

The expression for G is identical for that for μ_X in the "turnaround method" when $R=R_0$. This must be true, since in that case T_R goes to infinity.

Numerically

$$G = \frac{[(0.170\pm0.001)\ \mathrm{m}]^{3/2}}{[2\times10^{-7}\ \mathrm{N/A^2}]^{1/2}}\ \frac{2\pi}{(0.546\pm.003)\ \mathrm{sec}}\ \left[(4.95\pm0.1)\times10^{-8}\ \mathrm{kg\ m^2}\right]^{1/2}$$

then standard error propagation and reduction of the units give

$$G = (0.401 \pm 0.006)\ \mathrm{Am}^2$$

which is a 1.5% uncertainty. For F we find numerically :

$$F = \left\{1.000 - \left[\frac{(0.550\pm.004)\ \mathrm{sec}}{(1.084\pm.004)\ \mathrm{sec}}\right]^2\right\}^{1/2}$$

The central value here is 0.862. One can easily use a pocket calculator to see the effects of the permitted statistical variations in each of the two places above. This shows that the effect of the numerator uncertainty is essentially ± 0.0022, while that of the denominator is ± 0.0013. Combining these statistically gives an net uncertainty in F of 0.0026, so that the fractional uncertainty in F is 0.0033. [An analysis of this by calculus is straightforward, but cumbersome] Then the fractional uncertainty in μ_X is practically that in G. We find:

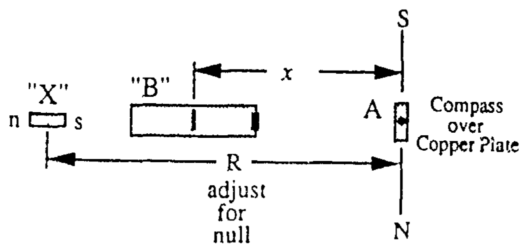
$$\mu_X = (0.862 \pm 0.0026)\,(0.401 \pm 0.006)\ \mathrm{Am} = (0.346\pm.005)\ \mathrm{A\,m^2}.$$

By way of comparison, measurement of the same magnet X using Fluxgate Magnetometry (at a distance of around 16 cm) gave $\mu_X = (0.345 \pm .003)\ \mathrm{A\,m^2}$.

PART 2 : DISTANCE DEPENDENCE OF FIELD OF "B" UNKOWN

Method I (Close Distances) : Nulling of Transverse Static Deflection

Arrangement (top view)



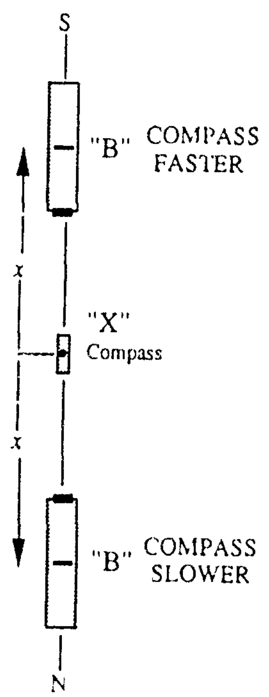
Equation

$$B_X(x) = \frac{2K\mu_X}{R^3}$$

Method II (Intermediate Distances) : Differential $1/T^2$ Technique

General Relation : $T = T_X$; B_h =local (horiz.) field $\left\{ (2\pi T)^2 = \frac{\mu_X B_h}{I_X} \right.$

Arrangement (top view)



DEFINE

$$\Delta(1/T^2) \equiv (1/T^2)_{faster} - (1/T^2)_{slower}$$

THEN:

$$\Delta(1/T^2) = \frac{\mu_X \Delta B_h}{4\pi^2 I_X} \quad \text{where } \Delta B_h = 2B_x(x)$$

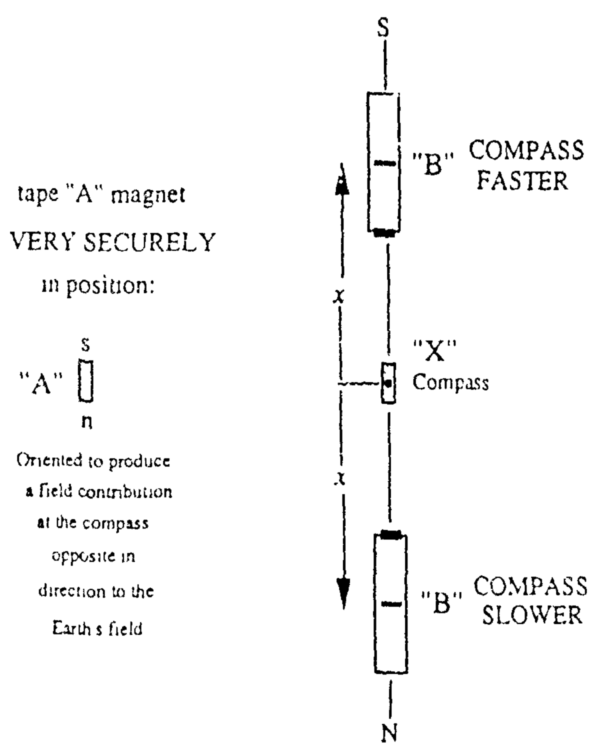
$$\boxed{B_x(x) = \frac{2\pi^2 I_X}{\mu_X} \Delta(1/T^2)}$$

"Master Equation"

Method III (Large Distances) :

Differential $1/T^2$ Technique with Partial "Bucking" of the Earth's Field

Arrangement (top view)



"Master Equation"

$$\boxed{B_x(x) = \frac{2\pi^2 I_x}{\mu_x}\,\Delta(1/T^2)}$$

remains the same

Use only partial buckout --(slow natural oscillations typically by a factor of 2)

In working at a given distance x, $\Delta(1/T^2)$ must be constant (independent of the "bucking").

$\Delta(1/T^2) = \text{const}$

$\Delta T/T^3 = \text{const.} \longrightarrow \boxed{\Delta T \propto T^3}$

Sample Experiment

Method I $$B_X(x) = \frac{2K\mu_X}{R^3} = \frac{[(2\times10^{-7})\text{T m/A}][0.346\pm0.005]\text{Am}^2}{[\text{R (m)}]^3}$$

DATA TABLE FOR METHOD I

measured data		calculated	standard error propagation	see below	
x (m)	R (m)	$B_X(x)$ $(10^{-7}$T)	ΔB/B	$4\Delta x/x$	$(\Delta B/B)_{eff}$
.062±.001	.112±0.112	493.	.031	.065	.072
.0705±.0015	.133±.0015	294	.019	.085	.087
.0845±.0015	.167±.002	149	.039	.071	.081
.102±.0015	.206±.005	79	.074	.059	.095

The uncertainty in R includes the ruler reading error, together with the imprecision in locating the null position, the latter effect becoming predominant at larger x. The R uncertainty, together with the small uncertainty in μ_X define the ΔB/B values listed in the 4th column.

Of course there are also the uncertainties in the x values, which we could represent graphically by horizontal error bars. Since this is technically awkward, we choose instead to define an effective vertical uncertainty. Since it turns out that the log-log plot slope is about -4, a given fractional error in x corresponds to 4 times as much in B(x). These fractional errors have been tabulated in the 5th column. From this it is clear that we should take the effective ΔB/B as the square root of the sum of the squares of thecontributions in colums 4 and 5. These values, listed in column 6, form the basis for the error bars used Though we would certainly not expect a student to do this, we would expect him to be aware of the horizontal uncertainties.

Method II $$B_x(x) = \frac{2\pi^2 I_X}{\mu_X}\,\Delta(1/T^2) = (28.2\pm .51)\times10^{-7}\text{ Tesla sec}^2 \cdot \Delta(1/T^2)$$

● x = (.120±.001)m :

Data in seconds for 20 oscillations: Pocket Calculator Results:

$20\,T_{slow}$: 14.56, 14.50, 14.52, 14.58 T_{slow}= (.727±.0018)sec

$20\,T_{fast}$: 11.32, 11.34, 11.31, 11.28 T_{fast} = (.5656±.0013)sec

$\Delta(1/T^2)$ = [(3.1257±.0138)-(1.892±.0095)] sec^{-2} = (1.23±.017)sec^{-2}

⟶ $B_x(x)$ = (34.7±0.8)x10^{-7} Tesla

Introduced bucking magnet in transverse position to slow oscillations in Earth's Field to about 1.2sec

Master equation is still:

$$B_x(x) = \frac{2\pi^2 I_X}{\mu_X} \Delta(1/T^2) = (28.2\pm .51)\times 10^{-7} \text{ Tesla sec}^2 \cdot \Delta(1/T^2)$$

- $x = (.150\pm.001)$m :

Data in seconds for 20 oscillations: Pocket Calculator Results:

$20\,T_{slow}$: 27.90, 27.80, 27.78, 27.77 $T_{slow} = (1.391\pm.003)$sec

$20\,T_{fast}$: 19 56 19.66, 19.50, 19.64 $T_{fast} = (.9795\pm.0037)$sec

$\Delta(1/T^2) = [(1\ 0422\pm.0079)\text{-}(.5171\pm.0022)]\text{sec}^{-2} = (\ 525\pm.0082)\text{sec}^{-2}$

$\longrightarrow B_x(x) = (14\ 8\pm .35)\times 10^{-7}$ Tesla

- $x = (\ 170\pm\ 001)$m :

Data in seconds for 20 oscillations. Pocket Calculator Results:

$20\,T_{slow}$: 24 97, 24.97, 24 87 $T_{slow} = (1.2468\pm.0029)$sec

$20\,T_{fast}$: 20 55, 20.46, 20.79, 20 65 $T_{fast} = (1.0306\pm\ 00708)$sec

$\Delta(1/T^2) = [(\ 9415\pm\ 013)\text{-}(.6433\pm.0030)]\text{sec}^{-2} = (\ 298\pm\ 013)\text{sec}^{-2}$

$\longrightarrow B_x(x) = (8.4\pm 0\ 4)\times 10^{-7}$ Tesla

- $x = (.190\pm\ 001)$m :

Data in seconds for 20 oscillations: Pocket Calculator Results:

$20\,T_{slow}$: 17.17, 17.15, 17.11, 17.10 $T_{slow} = (\ 8566\pm\ 0017)$sec

$20\,T_{fast}$: 16.01, 15.93, 15 91, 15.92 $T_{fast} = (\ 797\pm.0029)$sec

$\Delta(1/T^2) = [(1.574\pm\ 028)\text{-}(1\ 3628\pm\ 0053)]\text{sec}^{-2} = (\ 2112\pm\ 029)\text{sec}^{-2}$

$\longrightarrow B_x(x) = (6.0\pm 0.8)\times 10^{-7}$ Tesla

- $x = (\ 220\pm.001)$m :

Data in seconds for 20 oscillations: Pocket Calculator Results:

$20\,T_{slow}$: 23 80, 23 76, 23 70 $T_{slow} = (1.1877\pm.00252)$sec

$20\,T_{fast}$: 22 27, 21 98, 21.86, 21.94 $T_{fast} = (1.1006\pm.0089)$sec

$\Delta(1/T^2) = [(.8255\pm\ 0134)\text{-}(\ 7089\pm.0030)]\text{sec}^{-2} = (.1166\pm.014)\text{sec}^{-2}$

$\longrightarrow B_x(x) = (3\ 3\pm 0.4)\times 10^{-7}$ Tesla

DATA TABLE FOR METHODS II and III

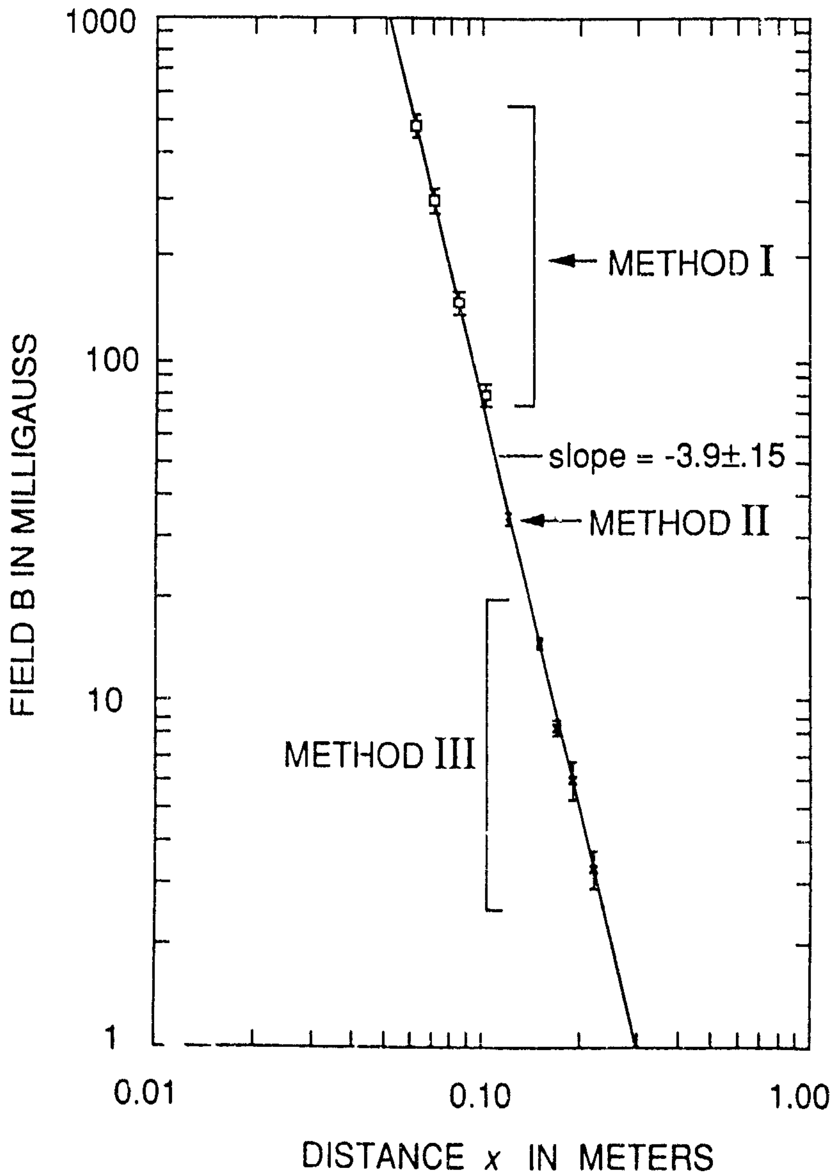
x (m)	Method	calculated $B_x(x)$ (10^{-7} T)	standard error propagation ΔB/B	see above $4\Delta x/x$	see above $(\Delta B/B)_{eff}$
.120± 001	II	34 7	.023	.033	.040
150± 001	III	14.8	.024	.027	.036
.170±.001	III	8.4	.05	.024	.0̄5
.190±.001	III	6.0	.13	021	.13
.220± 001	III	3.3	.12	.018	.12

The equivalent vertical uncertainties have calculated as before and tabulated in the last column above These give the error bars on the log-log plot shown on the next page. The three different methods are nicely consistent, and the whole data set well fits the power law indicated by the drawn line When this is done on the regular log paper (as provided), the easiest way in this case to get the slope is to use a pocket calculator to find the ratio of the log of the vertical rise ratio to that of the horizontal run ratio for the possible lines consistent with the errors. Since the line has to drop vertically through three decades in total, this is roughly

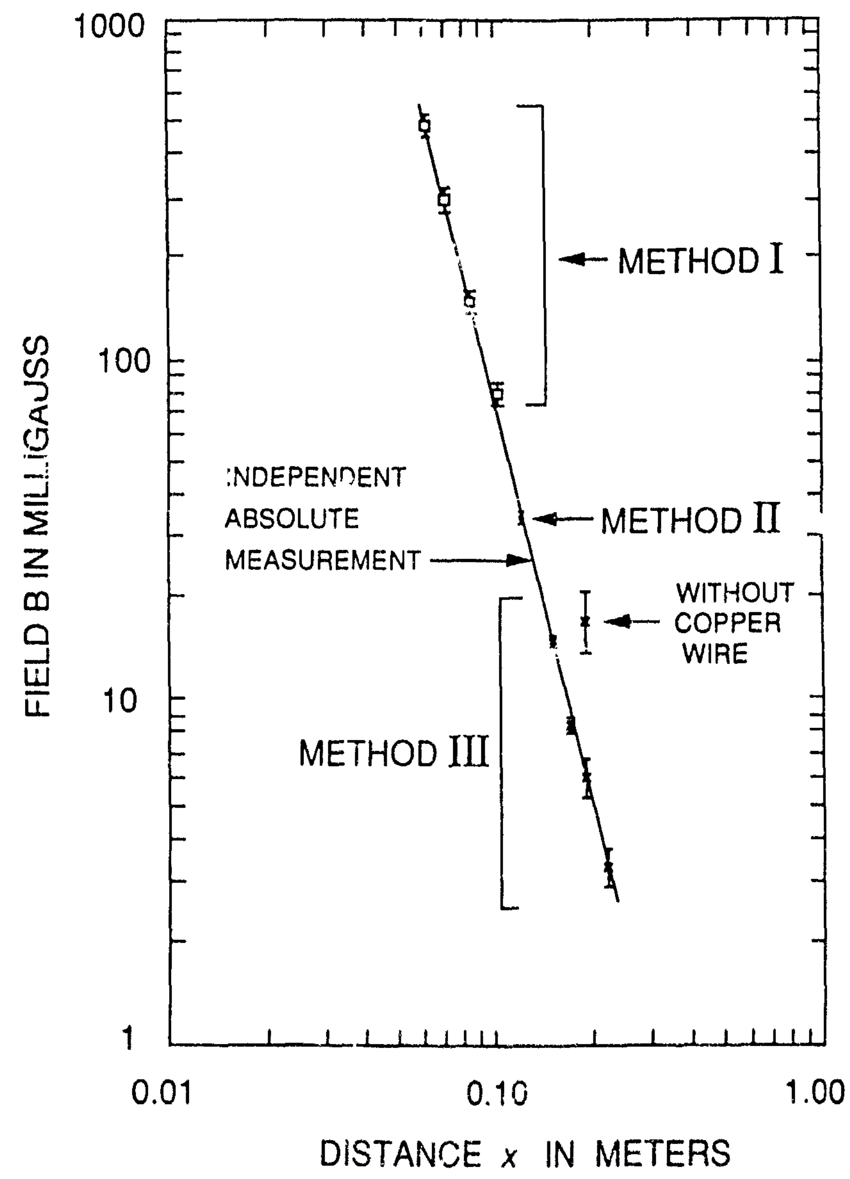
$$\text{slope} = \frac{-3}{\log_{10}\left[\frac{(0.30\pm 02)}{(051\pm 03)}\right]} = -3\,9 \pm 0.15$$

For this particular unknown, the fluxgate magnetometer data gave an effective exponent of -3 92 over the range from 0 07m to 0 22m. A more detailed absolute comparison with those measurements is shown on the second graph Here the drawn line corresponds to the actual magnetometer data The student experiment is clearly doing an excellent job. Of particular interest is the next to the lowest point (x=0.19m) For this point, the "buckout" magnet had been moved out a little bit so that the natural compass period in the Earth's field was about 0.89 sec., which was close to the period of the "pendulum mode". This was done deliberately to test the effectiveness of the copper wire "mode-decoupler". The point at x=0.19 m which is <u>on</u> the line was taken <u>using</u> the decoupler. The point at the same x value which is almost a factor of 3 higher than the line was taken <u>without</u> the decoupler

This shows that the decoupler is both effective and important. Without it, the "fast" and "slow" measurements are effected <u>differently</u> by the coupling to the pendulum mode. Then the small difference between them can be <u>very</u> poorly determined



1000
100
10
1
0.01
0.10
1.00
FIELD B IN MILLIGAUSS
DISTANCE x IN METERS
METHOD I
slope = -3.9±.15
METHOD II
METHOD III



1000
100
10
1
0.01
0.10
1.00
FIELD B IN MILLIGAUSS
DISTANCE x IN METERS
METHOD I
METHOD II
METHOD III
INDEPENDENT
ABSOLUTE
MEASUREMENT
WITHOUT
COPPER
WIRE

Experimental Problem 2: Grading Scheme

Part 1

2.5 points	Show how μ_X is calculated, clearly labeled diagram
1.5 points	μ_X is correctly stated
0 - 1 points (sliding scale)	error analysis
0 - 1 points (sliding scale)	consistency with "correct" range

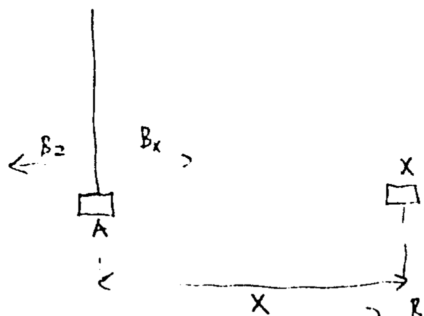
Part 2

1.0 points	A diagram of a technique that can be used
1.0 points	Correct measurements at 3 distances at least
0 - 1 points (sliding scale)	Accuracy of the result (correct value of p)
0 - 1 points (sliding scale)	Precision and error analysis

M 5

BKE-000

1.



$\Leftrightarrow B=0 \Leftrightarrow B_z = B_x$

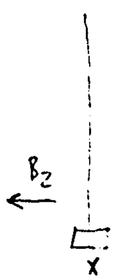
Nastavíme tak, aby $T \to \infty$ tj. tak, aby $B_z = B_x$

$$B_z = \frac{2\mu_x k}{x_1^3} = B_x$$

Rovnovážná poloha je $\perp$ k $\vec{B_z}$.

Změřeno $x = 14{,}4\ cm$

2.



$$T = 2\pi\sqrt{\frac{I_x}{\mu_x B_z}} \quad ; \quad B_z = \frac{2\mu_x k}{x_1^3}$$

$$T^2 = 4\pi^2 \cdot \frac{I_x x_1^3}{2\mu_x^2 k} \quad ; \ I_x \text{ známe}$$

$$\Downarrow$$

$$\mu_x = 2\pi \cdot T^{-1} \cdot \sqrt{\frac{I_x \cdot x_1^3}{2k}} \quad ; \ T \text{ změříme}$$

; x_1 změříme

		T (s)
20 kmitů	9,05 s	0,4525
40 kmitů	18,87 s	0,4718
80 kmitů	37,75 s	0,4719
40 kmitů	18,83 s	0,4708
40 kmitů	18,88 s	0,4720
		~~0,4718~~
40 kmitů	18,87 s	0,4718

$T = [0,4717 \pm 0,0003]$

$\mu_x = 0,3639\ \mathrm{H\,m^{-1}}$; hlavní chyba je od I_x ... chyba 2%

$\sqrt{\ }$ ⇓ chyba 1%

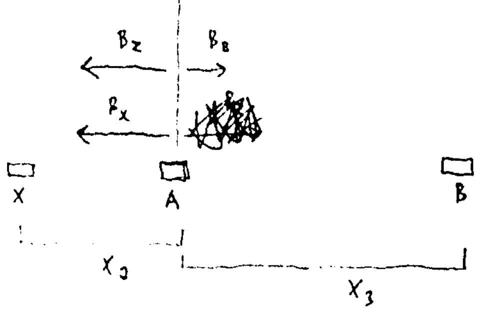
a od x ; chyba 0,5%

3/2 ⇓ 1%

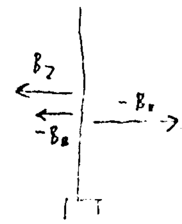
; chyba 2%

$\mu_x = [0,364 \pm 0,007]\ \mathrm{H\,m^{-1}}$; chyba 2%

3.



nebo



Nastavíme tak (jako 1.), aby $B_B = B_X + B_Z$; $B_Z = \frac{2 m_X K}{X_1^3}$

; $B_X = \frac{2 m_X K}{X_2^3}$

; $B_B = C \cdot X_3^n$

; $B_B = B_X + B_Z$

Změříme nějaké hodnoty:

a) $B_X = 0$ a $B_B = + B_Z$

$X_3 = 7{,}15$ cm $\quad |B_B| = \frac{2 m_X K}{X_1^3} \doteq 2{,}44 \cdot 10^{-5}$ T

b) $B_X = B_Z \quad \Rightarrow X_2 = 14{,}4$ cm

$X_3 = 5{,}90$ cm $\quad B_B = 2 B_Z = 4{,}88 \cdot 10^{-5}$ T

c) $X_2 = -13\,cm$ $\qquad B_X = -3{,}31 \cdot 10^{-5}\,T$

$X_3 = -9{,}24\,cm$ $\qquad B_B = -8{,}74 \cdot 10^{-6}\,T$

$$\Updownarrow$$

$X_3 = 9{,}25\,cm$ $\qquad B_B = 8{,}74 \cdot 10^{-6}\,T$

Jelikož lze očekávat blíže neurčený průběh magnet. indukce, ~~při~~ bylo by lepší určovat koeficient n pro vzd. ≫ vzdál. magnet. indukce, jinak nebude n = konst.

$\Downarrow$

Určíme n řešením z a), c) ~~dat~~ údaje:

	X_3 (cm)	B_B ($\cdot 10^{-6}$ T)
a)	7,15	24,4
c)	9,25	8,74

$$B_{Ba)} = C \cdot X_{3a)}^{n}$$
$$B_{Bc)} = C \cdot X_{3c)}^{n} \quad \Rightarrow \quad \frac{B_{Ba)}}{B_{Bc)}} = \left(\frac{X_{3a)}}{X_{3c)}}\right)^{n}$$

$$\Downarrow$$

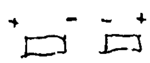
$$n = \frac{\ln\left(\frac{B_{Ba)}}{B_{Bc)}}\right)}{\ln\left(\frac{X_{3a)}}{X_{3c)}}\right)} \doteq \underline{\underline{-3{,}99}}$$

Chyba p?

- Hlavní od chyb v měření vzdálenosti
- cca 0,5% na 1 vzdálenost.
- 7x měř. vzd. a ³ mocnina → cca 4,5%
- chyba 5%

$$\boxed{p = -4 \pm 0{,}2}$$

To je reálné, neboť vztah $B_B = \frac{C}{x_S^4}$ odpovídá dvěma stejným magnetům daným v opačn. směrech.



⇓

S uvážením teorie lze očekávat $p = -4$.

(a), b), c) a tyto:)

Změřil jsem ještě body:

	x_3 (cm)	x_2 (cm)	B_B ($\cdot 10^{-6}$ T)
d)	−8,40	−12,5	−12,9
e)	−7,75	−12,0	−17,7

a závislost jsem vynesl na graf: – přiložen – viz $\boxed{\text{P. 7 of 6 Pages}}$

a)	7,15	∞	24,4
b)	5,90	14,4	44,6
c)	9,25	−13	8,76

} uvedeno již dříve

Z grafu lze odečíst parametr p:

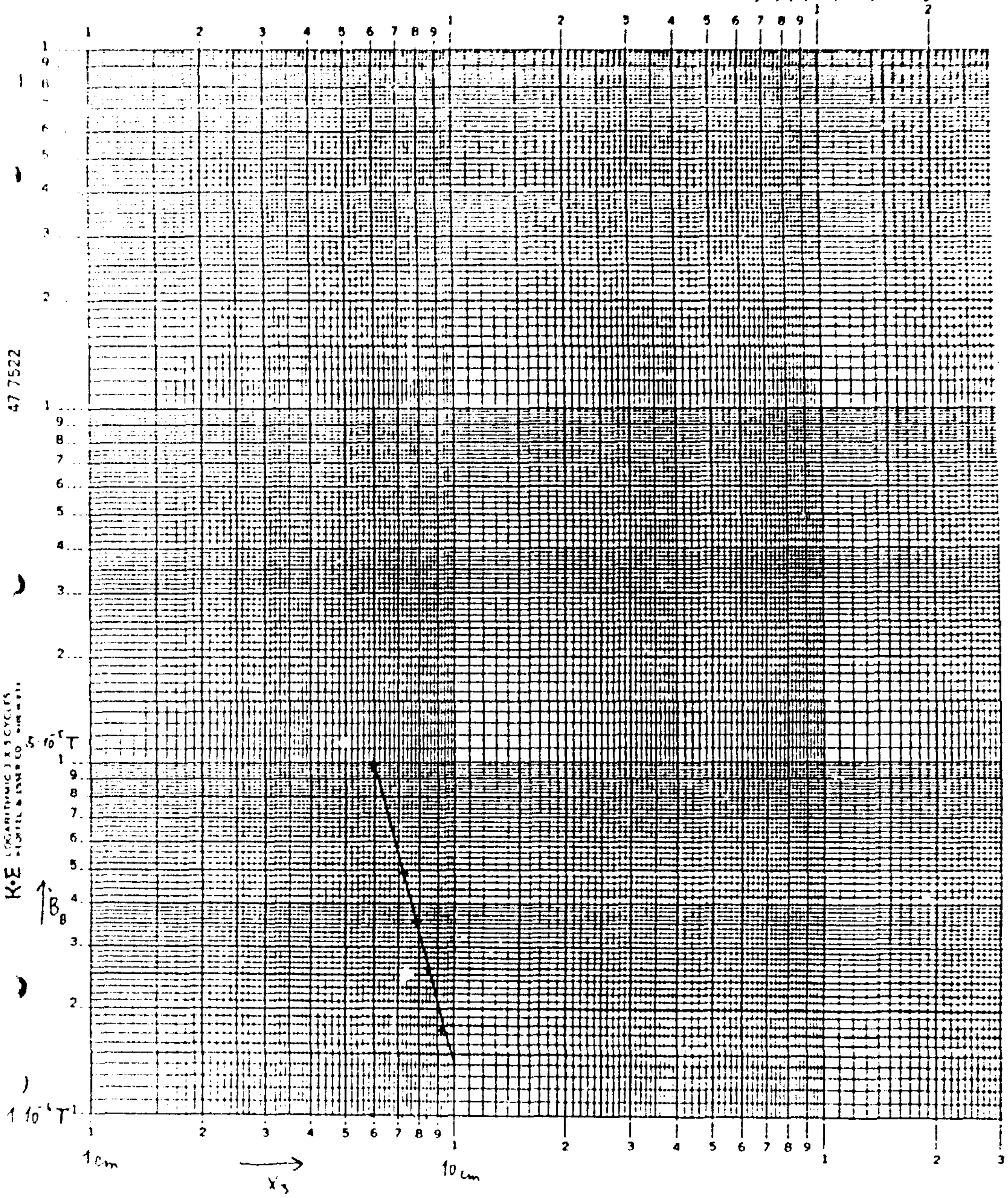
$$\boxed{p \doteq -4} \pm 0{,}2 \quad \text{– chyba } 5\%$$

Můžeme dokonce určit i konstantu C: $B_B \doteq C \cdot x_3^{-4}$
(i za předpokl. p = 4)

$$\Downarrow$$

$$C = \frac{B_B}{x_3^{-4}} = B_B \cdot x_3^{4} \doteq 6{,}4 \cdot 10^{-10}\ \mathrm{T\,m^4}$$

$$\boxed{C = (6{,}4 \pm 0{,}5) \cdot 10^{-10}\ \mathrm{T\,m^4}}$$


K·E
47 7522
$5 \cdot 10^{-5}$ T
$1 \cdot 10^{-6}$ T
B_8
1 cm
10 cm
x_3

SYLLABUS EXAMINATION-CORRELATION

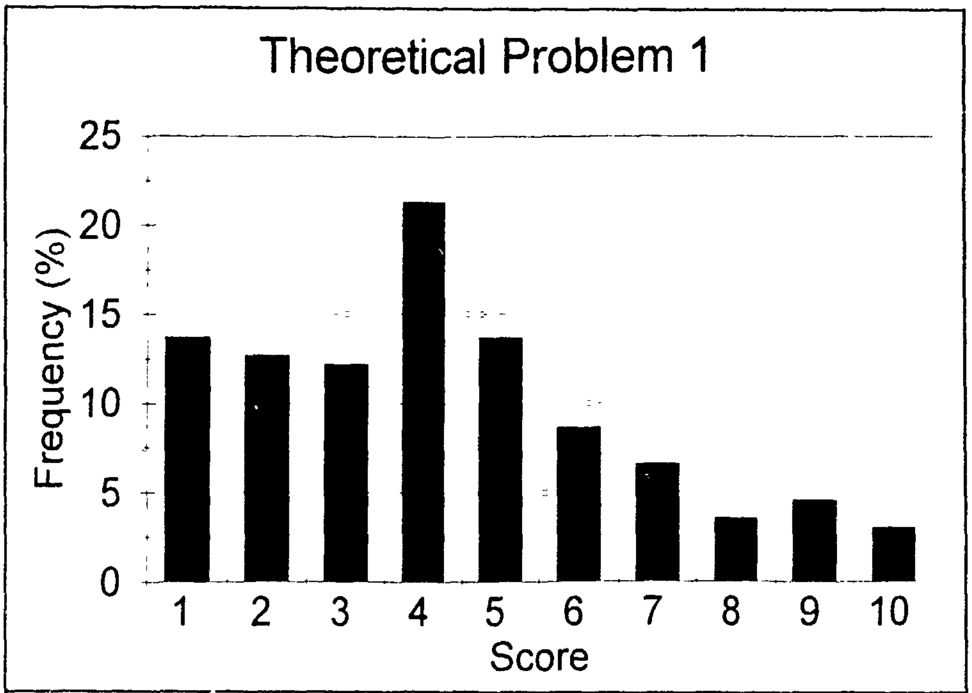
Subject-Matter Area

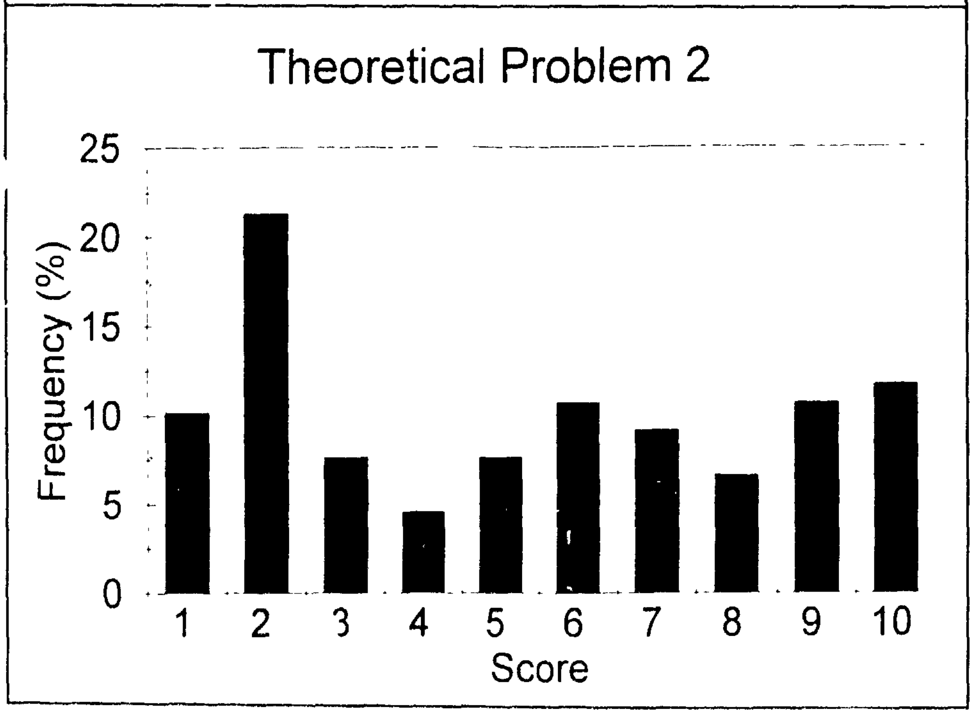
	1	2	3	4	5	6	7	8	9	10	11
Theory #1						x	x				(x)
Theory #2	x				x			x	x	x	
Theory #3	x					x		x	x		
Experiment #1				x			x				
Experiment #2		x			x		x				

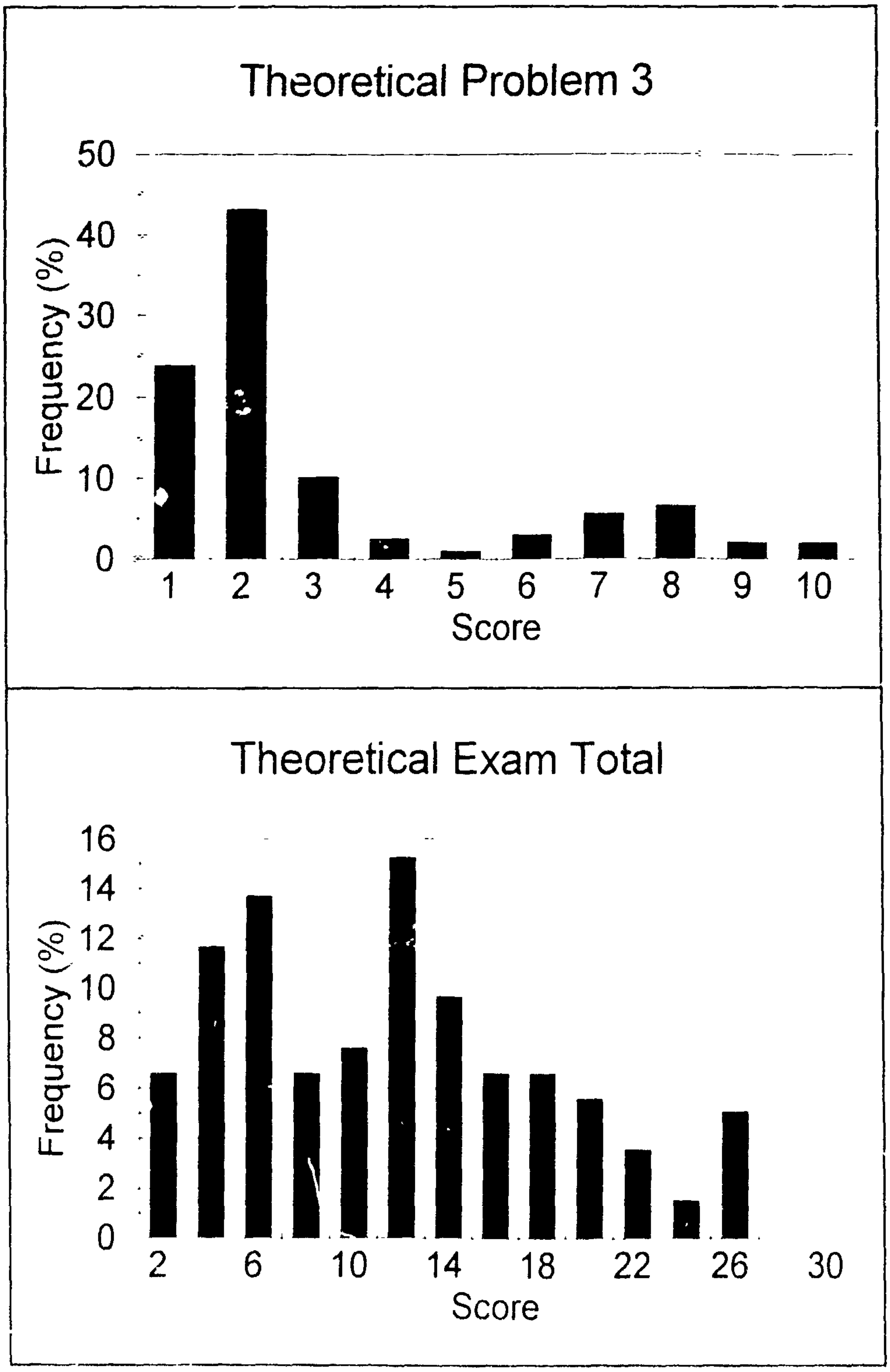
Key to Syllabus areas:

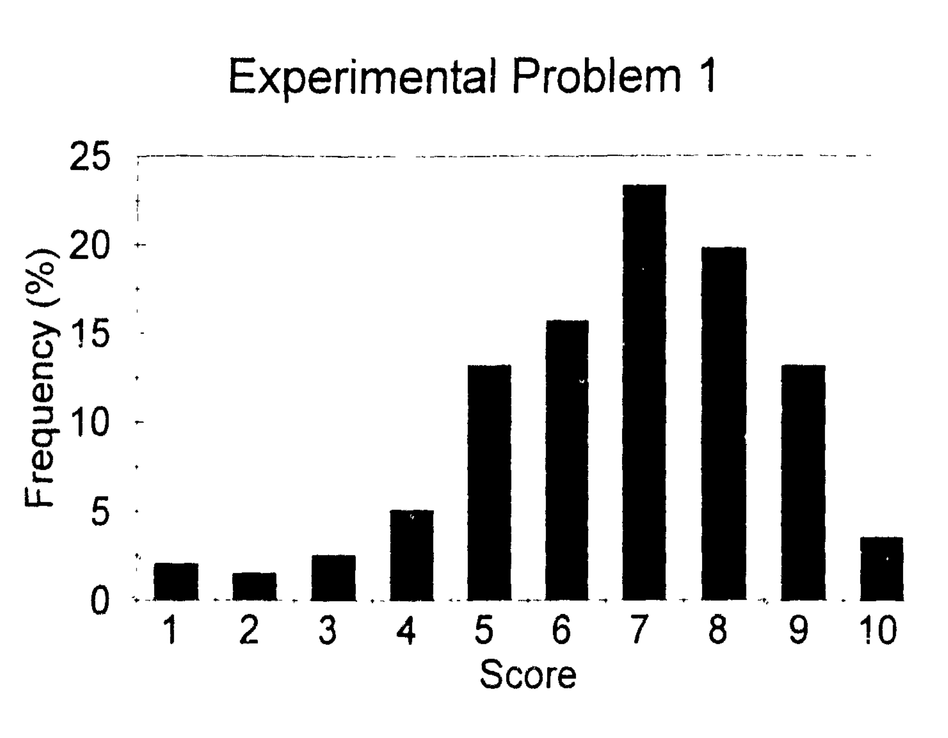
1. Mechanics
2. Mechanics of Rigid Bodies
3. Hydromechanics
4. Thermodynamics and Molecular Physics
5. Oscillations and Waves
6. Electric Charge and Electric Field
7. Current and Magnetic Field
8. Electromagnetic Waves (& Optics)
9. Quantum Physics
10. Relativity
11. Matter (including exponential decay)

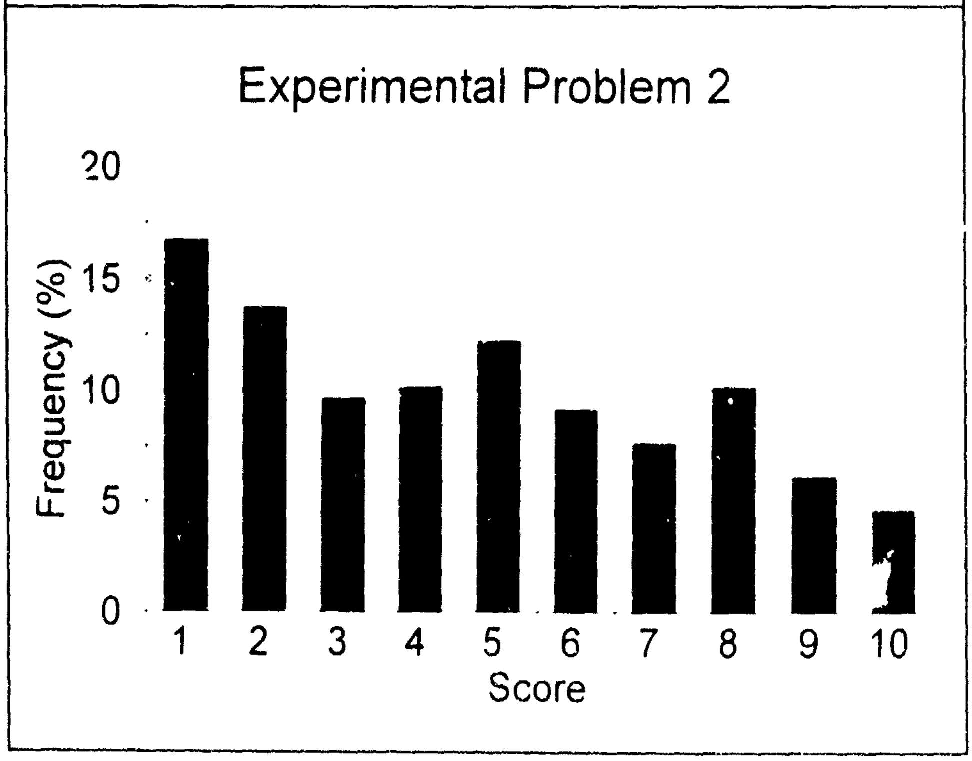
HISTOGRAMS OF THE SCORES

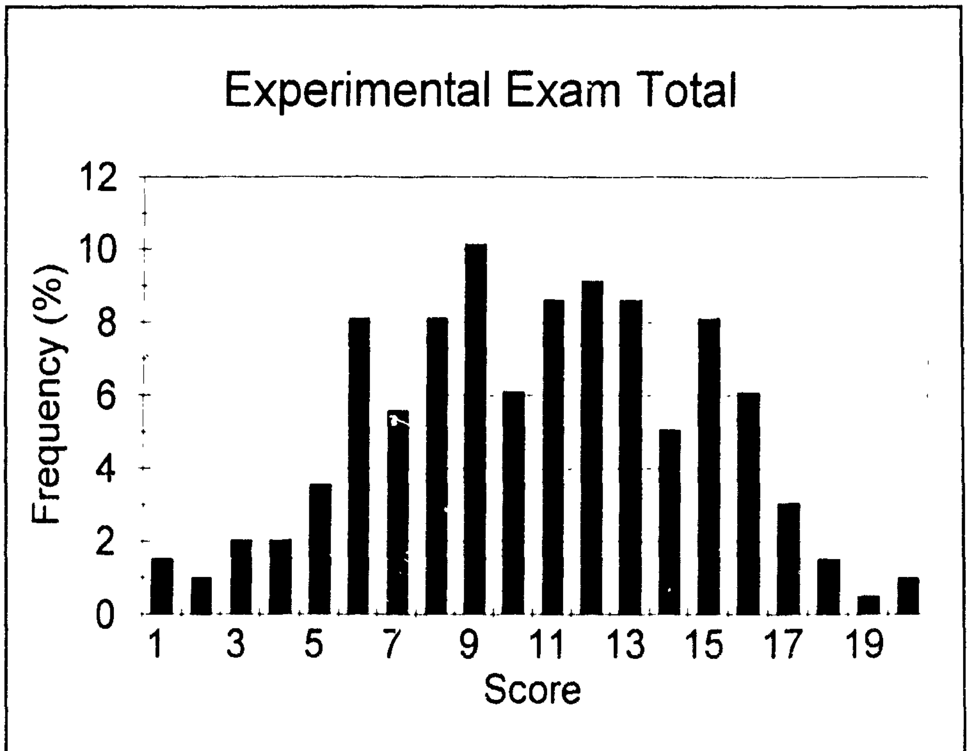




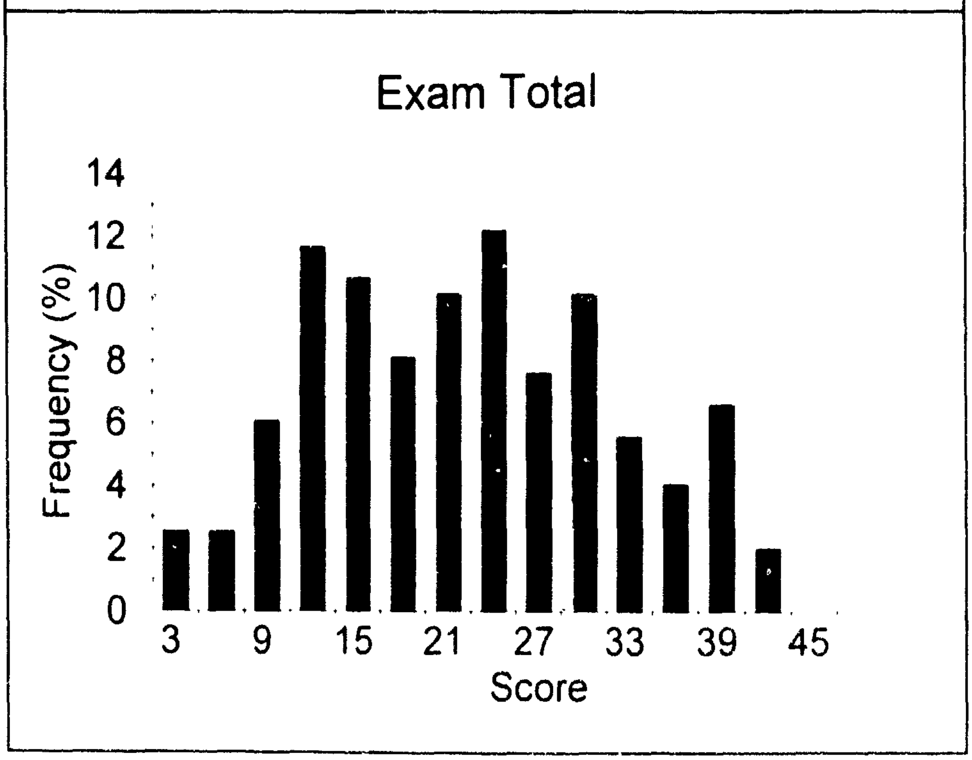

Theoretical Problem 3
Frequency (%)
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
Score
Theoretical Exam Total
Frequency (%)
16
14
12
10
8
6
4
2
0
2
6
10
14
18
22
26
30
Score


Experimental Problem 1
25
20
15
10
5
0
Frequency (%)
1 2 3 4 5 6 7 8 9 10
Score


Experimental Problem 2
20
15
10
5
0
Frequency (%)
1 2 3 4 5 6 7 8 9 10
Score



Experimental Exam Total
Frequency (%)
0
2
4
6
8
10
12
1
3
5
7
9
11
13
15
17
19
Score



Exam Total
Frequency (%)
0
2
4
6
8
10
12
14
3
9
15
21
27
33
39
45
Score

PART 3



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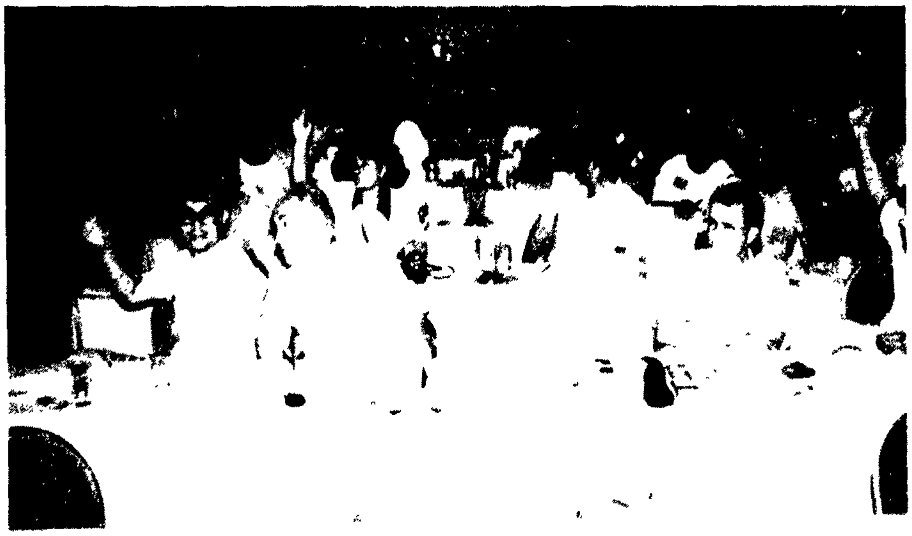

A vote during the International Board meeting

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Arthur Eisenkraft, Executive Director

It is with great pleasure that the Organizing Committee for the XXIV International Physics Olympiad announces that the United States of America will sponsor the 24th IPhO in Williamsburg, Virginia from the 10th to the 18th of July, 1993.

The Organizing Committee has been established by the American Association of Physics Teachers in conjunction with the American Institute of Physics. The Committee is chaired by Professor Leon Lederman of the University of Chicago. Executive Director of the Committee is Dr. Arthur Eisenkraft of the Bedford Public Schools, New York. He may be reached at

Dr. Arthur Eisenkraft
60 Stormytown Road
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Telephone: 914-941-1784
Telefax: 914-941-6533
E-mail: ae2@pinet.aip.org

The College of William and Mary, celebrating its Tercentennial in 1993, will be the host institution. Accomodations will be provided for students on campus while those for leaders will be at the Williamsburg Hospitality House nearby.

Adjacent to the college is Colonial Williamsburg, a restoration of the area originally settled in 1633, consisting of stately public buildings and a variety of colonial homes, shops, taverns, and gardens on or just off historic Duke of Gloucester Street. Pedestrians dressed in 18th century attire and craftsmen demonstrating 200 year old trades make the historic city come alive for visitors today. Summer in Williamsburg is generally warm and sunny, save for an occasional shower, making a stroll through the area a pleasant diversion.

Additional excursions are tentatively planned to the National Aeronautics and Space Administration facility at Langley, CEBAF (the Continuous Electron Beam Accelerator Facility),

Jamestown and Yorktown. Students and leaders will also have time to enjoy the ocean waters at Virginia Beach and test out the principles of physics in action at Busch Gardens Amusement Park The College of William and Mary also has excellent facilities for more impromptu recreation such as soccer games, tennis, and swimming

All teams will be issued a formal invitation according to the statutes of the International Physics Olympiad Teams should plan on arriving in the United States at Dulles International Airport in Washington, DC on Saturday, 10 July 1993 Transportation from the airport to Williamsburg will be arranged by the Organizing Committee and teams will be informed as these are completed. Additionally, if there are enough requests, the committee may be able to arrange transportation from Washington National Airport, Baltimore Washington International Airport, Norfolk International Airport, or Patrick Henry International Airport in Virginia. Teams chosing to arrive at other airports will need to provide their own transportation to one of the airports listed above or to Williamsburg, VA. Transportation will also be provided back to Washington, DC or to these airports at the close of the competition on Sunday, 18 July. The Committee hopes that teams will be able to extend their stay either before or after the competition to do some additional touring and sightseeing Teams that wish to tour will be provided with assistance in contacting their embassies in Washington to arrange hotels and transportation, as the Committee is unable to accomodate teams before 10 July and after 18 July. Please contact us as early as possible to request such assistance.

Tentative Program:

Arrival Date.	10 July 1993
Opening Ceremonies	11 July
First Meeting of International board	11 July (Afternoon)
Exams/ Excursions	12-16 July
Closing Ceremonies/ Banquet	17 July
Departure	18 July

Correspondence concerning the Olympiad may be directed to Dr Eisenkraft at the above address or to

Yvette A Van Hise, Correspondence Chair
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PO Box 119
Lincroft, NJ 07738 USA

Telephone: 908-842-8444
Telefax 908-219-9418
E-mail yxv@pinet aip org

The members of the Organizing Committee look forward to greeting the participants in the XXIV International Physics Olympiad in July 1993

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Arthur Eisenkraft, Executive Director

Dear Colleague:

It is with great pleasure that the Organizing Committee invites a team of students and leaders from your country to participate in the XXIVth International Physics Olympiad. The Olympiad will be held from July 10-18, 1993 at the College of William and Mary in Williamsburg, Virginia

As directed in the statutes of the International Physics Olympiad, the five students who represent your country should be secondary school students. You may choose students who have completed their secondary school studies in 1993, but students who have begun their university studies or who have reached the age of twenty by June 30, 1993 are not permitted to participate. Two pedagogical leaders are also invited to attend.

Opening ceremonies will be held on July 11th and closing ceremonies on July 17th. Teams are expected to arrive on July 10th and depart on July 18th Travel costs to the Washington, DC area and back must be provided by sponsors from your country, but once your team has arrived in the United States all costs associated with your participation in the Olympiad will be paid by the Organizing Committee. By direction of the statutes, the official languages of the competition will be English and Russian

We would appreciate your reply concerning the participation of your country no later than March 15, 1993 If you do not wish to send a team this year, please do send some observers (see information on enclosure) Communication may be by letter, telefax or electronic mail to Dr Eisenkraft at the above address or to Yvette Van Hise at the numbers listed below

It would indeed be an honor to welcome a team from your country to this prestigious international event and we look forward to hearing from you at your earliest convenience.

Sincerely,

Yvette A Van Hise,
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PO Box 119
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USA

Telephone 1-908-842-8444
Telefax 1-908-219 9418
E-mail yxv@aip org

Arthur Eisenkraft,
Executive Director

Enclosures

10-18 JULY 1993

A project of the American Association of Physics Teachers assisted by the American Institute of Physics

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Arthur Eisenkraft, Executive Director

Dear Colleague

On behalf of the Organizing Committee, I would like to express our pleasure that your country will be participating in the XXIVth International Physics Olympiad this summer in Williamsburg, Virginia. We expect over two hundred students and one hundred leaders and observers

I am writing to provide you with additional information regarding your delegation's preparation to attend the Olympiad I am also enclosing a form that requests information about your team and team leaders, as well as observers in the section noted "Special Information" please list any special dietary needs of the leaders or students, any allergies, medications that are being taken regularly, as well as any physical challenges of which we should be aware (for example, students confined to a wheelchair, etc) Also note that based on our better projections, we have reduced observer fees to $1450 per person

In your preparation, please designate one of your students to carry your country's flag into the Opening Ceremonies Following the banquet, we would like to have each country sing a folk song, play an instrument, perform a dance or entertain the group in some way. Please let us know if we can count on your participation in this performance

On one evening, leaders of the delegations will be hosted at local homes for dinner You may wish to bring a small, inexpensive gift from your country for your host family, but this is strictly voluntary

We ask that you return the questionnaires as soon as possible but in any case no later than early June, 1993 You may send them by mail, telefax or electronic mail at the addresses listed below.

We wish your team every success in the competition and we look forward to seeing you at the College of William and Mary from 10-18 July, 1993

Sincerely,

Yvette A Van Hise
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Enclosures

10 18 JULY 1993

A project of the American Association of Physics Teachers assisted by the American Institute of Physics

SITE AND ACCOMMODATIONS

The College of William and Mary, celebrating its Tercentennial in 1993, will be the host institution for the Olympiad. Accommodations will be provided for students on campus while those for leaders will be at the Williamsburg Hospitality House Hotel nearby. The number you should give to people at which you can be reached in case of an emergency is 1-804-221-3529 (voice phone) or 1-804-221-3540 (telefax).

Adjacent to the college is Colonial Williamsburg, a restoration of the area originally settled in 1633, consisting of stately public buildings and a variety of colonial homes, shops, taverns, and gardens on or just off historic Duke of Gloucester Street. Pedestrians dressed in 18th century attire and craftsmen demonstrating 200 year old trades make the historic city come alive for visitors today. Summer in Williamsburg is generally warm and sunny, save for an occasional shower, making a stroll through the area a pleasant diversion.

Additional excursions are tentatively planned to the National Aeronautics and Space Administration (NASA) facility at Langley, CEBAF (the Continuous Electron Beam Accelerator Facility), and Jamestown. Students and leaders will also have time to enjoy the ocean waters at Virginia Beach and test out the principles of physics in action at Busch Gardens Amusement Park. The College of William and Mary also has excellent facilities for more impromptu recreation such as soccer games, tennis, and swimming.

WEATHER

July is the height of summer in the United States. Although the climate of Williamsburg is generally mild, delegations should pack lightweight clothing for hot and humid weather, around 27-32 degrees Celsius. Since many of the meeting rooms and examination rooms are air conditioned, a light sweater is also advisable. To be prepared for an occasional shower, participants should also pack umbrellas or lightweight raincoats.

ATTIRE

Most of the Olympiad events require only casual attire, both for students and leaders. However, several events require special attire.

The Opening and Closing Ceremonies and the Banquet require more formal attire: jacket and tie for the gentlemen and dresses/ skirts for women.

Students and leaders should bring **bathing suits (swimsuits)** for the trips to Virginia Beach and Water Country Amusement Park. The latitude of Williamsburg can make the sun quite strong during the day and a good **sunscreen** is strongly suggested.

ARRIVAL OF TEAMS

Teams should plan on arriving in the United States at Dulles International Airport in Washington, DC on Saturday, 10 July 1993. Transportation from the airport to Williamsburg will be arranged by the Organizing Committee and teams will be informed as these are completed. Additionally, if there are enough requests, the committee may be able to arrange transportation from Washington National Airport, Baltimore Washington International Airport, Norfolk International Airport, or Patrick Henry International Airport in Virginia. Teams choosing to arrive at other airports will need to provide their own transportation to one of the airports listed above or to Williamsburg, VA.

Transportation will also be provided back to Washington, DC or to these airports at the close of the competition on Sunday, 18 July. The Committee hopes that teams will be able to extend their stay either before or after the competition to do some additional touring.

and sightseeing Teams that wish to tour will be provided with assistance in contacting their embassies in Washington to arrange hotels and transportation, as the Committee is unable to accommodate teams before 10 July and after 18 July Please contact us as early as possible to request such assistance

MONEY

Participants in the XXIVth IPhO, excluding observers, will be given some pocket money upon their arrival at Williamsburg The currency in the United States is the US dollar and each participant will be given $50 00 for unrestricted personal use

Money and traveller's checks are exchanged at local banks and in most hotels However, the transaction fee for changing foreign currencies to US dollars is quite high You may wish to consider changing your money before your arrival in the United States

Many shops take traveller's checks if they are drawn in United States denominations These can be arranged at your local bank before leaving your home country

In addition, most commercial establishments in the United States accept credit cards: Visa, Mastercard, and American Express being almost universally accepted

Williamsburg is a major shopping location, with many interesting and unique stores Also, the trips to Busch Gardens, Water Country and Virginia Beach will offer opportunities to purchase souvenirs

VISAS

Leaders should be sure to check with the nearest American diplomatic mission in your home country to see whether visas are required to enter the United States If they are and a letter is required from the Organizing Committee to assist in obtaining visas, please let us know by telecommunications (fax or e-mail) as soon as possible Include a working fax number at which you may be reached and letters will arrive promptly

COMPUTERS

Computers available for leaders' use will be MS DOS compatible machines equipped with hard drives and 3 5" and 5 25" disk drives Participants are asked to bring their own software for the translation of problems Assistants will be available and participants should plan on testing their software in the machines to be used immediately upon arrival at the Olympiad

OBSERVERS

Observers are welcome to participate in all the social events of the Olympiad The fee per person will be $1450 US The preferred method of payment is by an international money order or a cashiers' check in US dollars drawn on a United States bank The check or money order should be made out to the American Association of Physics Teachers

The second best method would be by Visa or Mastercard In order to process the charges, please include the following information

1. Name of the credit card holder as it appears on the credit card
2. Credit card name (Visa or Mastercard) and card number
3. Expiration Date
4. As many telephone numbers as possible (work phone numbers, fax numbers and e mail numbers) as well as a home address and a work address

The least preferred method of payment is by wire transfer This can be quite costly and if you choose this method, you should be aware that there is a fee charged by both the

transferring and the receiving banks. The observers would be responsible for meeting both of these fees These funds are also not always accompanied by the appropriate documentation, making accounting procedures most difficult.

ALCOHOL AND TOBACCO POLICIES

The organizers ask that while visiting the United States, the delegations respect the country's alcohol and tobacco regulations.

No one under the age of 21 is allowed to consume alcoholic beverages in this country It is also prohibited for those over 21 years of age to supply alcoholic beverages to those under 21 years of age. Anyone who fails to observe these regulations automatically forfeits his or her right to participate in the IPhO.

Students under 18 years of age are not allowed to purchase tobacco products. Smoking at the College of William and Mary is permitted only in specifically designated areas. Most public buildings in the United States do not permit smoking

During the Olympiad, all meetings of the International Board as well as all meal functions will be non-smoking.

XXIVTH INTERNATIONAL PHYSICS OLYMPIAD
TENTATIVE PROGRAM OUTLINE

SATURDAY, JULY 10
- Arrival of teams
- Lunch
- Dinner

SUNDAY, JULY 11
- Breakfast (Commons for students, hotel for leaders)
- Opening Ceremony
- Reception (Leaders)
- Lunch
- Tour of Colonial Williamsburg (students)
- Meeting of International Board (Theoretical Exam)
- Dinner
- Evening free time for students, continuation of Board Meeting for leaders

MONDAY, JULY 12
- Breakfast
- Theoretical Exam (students)
- Tour of Colonial Williamsburg (leaders)
- Lunch
- Water Country Excursion
- Barbecue Dinner
- Evening: Demonstration Shows

TUESDAY, JULY 13
- Breakfast
- Excursion to Busch Gardens (full day for students, half day for leaders)
- Lunch at Busch Gardens
- Second Meeting of International Board (Experimental Exam)
- Dinner (Busch Gardens for students, hotel for leaders)
- Evening for students. Free

WEDNESDAY, JULY 14
- Breakfast
- Experimental Exam AM or PM (students)
- Excursion to CEBAF (leaders)
- Lunch
- Excursion to NASA (leaders and students)
- Deli Dinner
- Evening: Coffeehouse and Karaoke

THURSDAY, JULY 15
- Breakfast
- Excursion to CEBAF (students)
- Grade Discussions (leaders)
- Lunch
- Home Visit for dinner (leaders)
- Dinner on campus (students)
- Evening: Paper Olympics

FRIDAY, JULY 16
- Breakfast
- Grade discussions (leaders)
- Excursion to Sandbridge (students)
- Lunch
- Excursion to Virginia Beach (students)
- Meeting of International Board
- American Dinner Party

SATURDAY, JULY 17
- Breakfast
- Rehearsal for Closing Ceremony
- Free Time (soccer?)
- Closing Ceremony
- Reception
- Banquet and Country Entertainment

SUNDAY, JULY 18
- Breakfast
- Departure of teams

PLEASE FILL OUT THE FOLLOWING FORM AND RETURN IT TO YVETTE VAN HISE AS SOON AS POSSIBLE BUT NO LATER THAN JUNE 1, 1993.

PART 5

MINUTES

of the sessions of the International Board held during the XXIV International Physics Olympiad in Williamsburg

July 10 - 18, 1993

1. Participants.

The following countries participated in the 24th International Physics Olympiad:

Australia, Austria, Belgium, Bulgaria, Canada, China, Colombia, Croatia, Cuba, Cyprus, Czech Republic, Estonia, Finland, FRG, Great Britain, Greece, Hungary, Iceland, Indonesia, Italy, Kuwait, Lithuania, Mexico, Netherlands, Norway, Philippines, Poland, Romania, Russia, Singapore, Slovakia, Slovenia, South Korea, Spain, Suriname, Sweden, Thailand, Turkey, Ukraine, USA and Vietnam.

Four countries were represented by observers. They were:

Argentina, Israel, Portugal and Taiwan Ch.

In addition to the regular participants an observer from the European Physical Society was present (Dr. Lars Gislen—at the same time the head of the Swedish delegation).

2. Change in the Statutes.

Three months prior to the XXIV IPhO the Secretariat disseminated to all the delegations present at the XXIII IPhO the following proposals:

a) on official languages of the IPhO (in two versions — the only difference between both versions was in the number of languages in which the texts of the problems should be prepared);

b) on providing the delegation leaders with the texts of the problems two hours prior to discussion.

a) By majority of votes (26 to 24) the International Board decided to vote the version A (the texts of the problems have to be prepared in 5 languages). The following change in the Statutes has been accepted by qualified majority of votes:

Ch 4, par. 3 (second sentence)

Old version:
Normally each of them should be able to speak one of the working languages of the International Physics Olympiads.

New version:
Normally each of them should be able to speak English.

Ch. 5

Old version:
The working languages of the International Physics Olympiad are English and Russian. Problems and solutions have also to be translated into German and French.

New version:
The working language of the International Physics Olympiad is English. The competition problems should be prepared in English, Russian, German, French and Spanish. The solutions to them should be prepared in English; the organizers, however, may prepare those documents in other languages as well.

Ch. 10

Old version:

e) The organizer chooses (according to # 7 and the list of physics contents in the Appendix to these Statutes) the problems and ensures the translation of the chosen problems and their solutions into the languages set out in # 5. ....

New version:

e) The organizer chooses (according to # 7 and the list of physics contents in the Appendix to these Statutes) the problems and ensures their proper formulation in English and in other languages set out in # 5. ....

Old version:

g) The organizer must supply interpreters for the working languages who are to be available at the sessions of the International Board. The interpreters should be able to cope with physical terminology.

New version:
This point is cancelled entirely. In consequence the lettering of the next points is changed: the points denoted by h, i, k and l receive the letters g, h, i and k, respectively.

Ch. 12

Old version:
The delegation leaders are responsible for the proper translation of the problems from the languages mentioned in # 5 to the mother tongue of the participants

New version:
The delegation leaders are responsible for the proper translation of the problems from English or other languages mentioned in # 5 to the mother tongue of the participants.

Ch. 18

Old version:
The originals of these Statutes are written in English and Russian.

New version:
The original of these Statutes is written in English.

Voting: in favour of the proposal - 32, against - 4, abstained - 6 (32 is greater than 2/3 of votes).
and

b) The proposal on providing the delegation leaders with the texts of the problems two hours prior to discussion was rejected (the number of votes in favour of the proposal was less than 2/3 of votes required by the Statutes).

3. Protests.

a) Before discussing the changes in the Statutes the Russian delegation lodged its protest against elimination of the Russian language from the sessions of the International Board. The protest has not been accepted.
b) The Chinese delegation lodged its protest against using the name "Taiwan" since this name can be considered as formal recognition of two Chinese states. The protest was not considered. The International Board accepted by acclamation that the problem should be solved by the delegations directly affected (possibly with help of the Secretariat of the IPhO).
c) The Iranian delegation did not receive American visas (the Iranian delegation applied for visas in the American Embassy in Italy on the way from Iran to the USA). In consequence Iran had no chance to participate in the XXIV IPhO. The Secretary of the IPhOs got a letter from the Iranian delegation on that matter. The letter was presented at the session of the International Board, held on July 17. Dr. Arthur Eisenkraft described the efforts of the Organizing Committee to solve the problem. The International Board accepted his explanation by acclamation and later — taking into account that the Iranian pupils should not suffer for any "unhappy events" — unanimously accepted the following suggestion of the Organizing Committee

The theoretical examination will be sent to the Iranian leaders. The Organizing Committee will ask them to translate andalso to administer and grade the exams according to the grading scheme accepted at the XXIV IPhO. The leaders will send the names and scores on the theoretical exam to the Organizing Committee. These scores will be compared with the official scores of the XXIV IPhO. Unofficial recognition will be provided to these students including certificates, medals and prizes (if earned) and placement of their names in the proceedings. Small mementos of the Olympiad including T-shirts and bags will be sent.

4. Dr. Waldemar Gorzkowski was unanimously reelected as Secretary General of the IPhO for the term July 17, 1993 through July 17, 1998.

5. The Secretary of the International Physics Olympiads reminded delegations that the Secretariat of the IPhOs always welcomes suggestions, comments and remarks concerning the Statutes and the Syllabus. All the suggestions received in written form before December 31, 1993 will be disseminated to all the delegations not later than in March 1994.

6. The results of marking the papers by the organizers were discussed. Some small clerical mistakes were corrected. The final version of the results was unanimously accepted. The best score (40.65 points) was achieved by Junan Zhang from China and Harald Pfeiffer from Germany (Absolute Winners of the XXIV IPhO). The following limits for awarding the medals were established according to the Statutes:

36 points - Gold Medal
31 points - Silver Medal
26 points - Bronze Medal
20 points - Honourable Mention

According to these limits 17 Gold Medals, 16 Silver Medals, 32 Bronze Medals and 38 Honourable Mentions were awarded. The list of the prize-winners was distributed to all the delegations.

7. In addition to the regular prizes a number of special prizes were awarded.
   a) The top student from each participating team was awarded a special prize of a laser for the student and a laser for the student's high school teacher.
   b) additional special prizes were awarded as follows:
   theoretical problem #2: Lajos Molnar - Hungary
   Andrzej Komisarski - Poland
   theoretical problem #3: Thomas Dent - Great Britain

practical problem #1: Gabor Veres - Hungary
practical problem #2: Andras Major - Germany
the EPS award for the best balance of theory and experiment:
Linbo Li - China.

8. During the 24th IPhO the daily newspaper "Chaos" was published. This newspaper presented the everyday olympic life and it was distributed to all the participants, delegation heads, pedagogical leaders and accompanying persons free of charge.

9. Prof. Anthony French informed the International Board that the IPhO has received the "ICPE Medal for Physics Teaching" from the International Commission on Physics Education of IUPAP. The medal is transferred each year to a representative of the host country for the following year. At the closing ceremony the medal was transferred from the organizers of the XXIV IPhO to the representatives of China where the next Olympiad will be organized. Similar medals were prepared for three persons especially active in the initial period of the IPhOs: Prof. Czeslaw Scislowski from Poland (organizer of the I IPhO in Warsaw in 196., Prof. Rudolf Kunfalvi from Hungary (organizer of the II IPhO in Budapest in 1968) and Prof. Rostislav Kostial from former Czecho-Slovakia (organizer of the III IPhO in Brno in 1969).

10. The Lithuanian delegation expressed deep thanks on behalf of all the members of the International Board to Dr. Arthur Eisenkraft and to the members of the Organizing Committee for excellent preparation and execution of the XXIV International Physics Olympiad. Additionally, the Lithuanian delegation decorated Dr. Arthur Eisenkraft with a Lithuanian medal of merit and a sash in recognition of his great and perfect work.

11. Prof. Shen Ke-Qi (China), acting on behalf of the organizers of the next International Physics Olympiad, announced that the XXV International Physics Olympiad will be organized in Beijing (China) on July 12-19, 1994 and cordially invited all the participating countries to attend the competition.

Dr. Waldemar Gorzkowski
Secretary of the IPhO

Dr. Arthur Eisenkraft
Executive Director of the XXIV IPhO

Williamsburg, July 18, 1993

Citation for the Presentation of
The Medal of the International Commission on Physics Education
to
The International Physics Olympiad

The Medal of the International Commission on Physics Education of the International Union of Pure and Applied Physics was established in 1979 for the purpose of recognizing contributions to physics education which are 'major in scope and impact and which have extended over a considerable period.' At its meeting in Torun in August 1991 the International Commission on Physics Education awarded its medal for 1991 to the International Physics Olympiad.

The International Physics Olympiad has been held since 1967, the idea for it having originated at a conference of the Czechoslovakian Physical Society in Prague in a discussion among Rotislav Kostial (Brno), Rudolf Kunfalvi, (Budapest), and Czeslav Scislowski (Warszawa). The first Olympiad was organized by Czeslav Scislowski in Warszawa in 1967, with Bulgaria, Czechoslovakia, Hungary, Poland and Romania participating. Over the past twenty-four years the Physics Olympiad has gradually grown in size and scope, with over thirty countries on five continents currently participating. The International Physics Olympiad has become an achievement of world-wide impact, and physics educators from various countries around the world have attested to the strong influence it has had in stimulating interest in physics among both students and teachers in their countries.

October 18, 1991

E. Leonard Jossem
Chairman

Jorge Barojas Weber
Secretary

STAUTES OF THE INTERNATIONAL PHYSICS OLYMPIADS

(Adopted in Sigtuna, Sweden, June 1984;
changes: Bad Ischl, Austria, June 1988;
Warsaw, Poland, July 1989;
Groningen, The Netherlands, 1990;
Havana, Cuba, July 1991;
Helsinki, Finland, July 1992;
Williamsburg, Virginia - USA, July 1993)

1

In recognition of the growing significance of physics in all fields of science and technology, and in the general education of young people, and with the aim of enhancing the development of international contacts in the field of school education in physics, an annual physics competition has been organized for secondary school students, the competition is called the "International Physics Olympiad" and is a competition between individuals.

2

The competition is organized by the Education Ministry or another appropriate institution of one of the participating countries on whose territory the competition is to be conducted. Hereunder, the term "Education Ministry" is used in the above meaning. The organizing country is obliged to ensure equal participation of all the delegations, and to invite all the participants of any of the last three competitions. Additionally, it has the right to invite other countries.

Within five years of its entry in the competition a country should declare its intention to be the host for a future Olympiad. This declaration should propose a timetable so that a provisional list of the order of countries willing to arrange Olympiads can be compiled.

A country which refuses to organize the competition may be barred from participation, even if delegations from that country have taken part in previous competitions.

3

The Education Ministries of the participating countries, as a rule, assign the organization, preparation and execution of the competition to a physics society or another institution in the organizing country. The Education Ministry of

the organizing country notifies the Education Ministries of the participating countries of the name and address of the institution assigned to the organization of the competition.

4

Each participating country sends a team consisting of students of general or technical secondary schools, i.e. schools which cannot be considered technical colleges. Also students who finished their school examination in the year of the competition can be members of a team as long as they do not start the university studies. The age of the participants should not exceed twenty on June 30th of the year of the competition. Each team should normally have 5 members.

In addition to the students, two accompanying persons are invited from each country, one of whom is designated delegation head (responsible for whole delegation), and the other — pedagogical leader (responsible for the students). The accompanying persons become members of the International Board, where they have equal rights.

The delegation head and pedagogical leader must be selected from specialists in physics or physics teachers, capable of solving the problems of the competition competently. Normally each of them should be able to speak English

The delegation head of each participating team should, on arrival, hand over to the organizers a list containing personal data on the contestants (surname, name, date of birth, home address, type and address of the school attended).

5

The working language of the International Physics Olympiad is English. The competition problems should be prepared in English, Russian, German, French and Spanish. The solutions to them should be prepared in English; the organizers, however, may prepare those documents in other languages as well.

6

The financial principles of the organization of the competition are as follows:

* The Ministry which sends the students to the competition covers the return travel costs of the students and the accompanying persons to the place at which the competition is held.

* All other costs from the moment of arrival until the moment of departure are covered by the Ministry of the organizing country. In particular, this concerns the costs for board and lodging for the students and the accompanying persons, the cost of excursions, awards for the winners, etc

7

The competition is conducted on two days, one for the theoretical competition and one for the experimental competition. There should be at least one day of rest between these two days. The time allotted for solving the problems should normally be five hours. The number of theoretical problems should be three and the number of experimental problems one or two.

When solving the problems the contestants may make use of tables of logarithms, tables of physical constants, slide-rules, non-programmable pocket calculators and drawing material. These aids will be brought by the students themselves. Collections of formulae from mathematics or physics are not allowed.

The theoretical problems should involve at least four areas of physics taught at secondary school level (see Appendix). Secondary-school students should be able to solve the competition problems with standard high school mathematics and without extensive numerical calculation.

The host country has to prepare one spare problem which will be presented to the International Board if one of the first three theoretical problems is rejected by two thirds of members of the International Board. The rejected problem cannot be considered again.

8

The competition tasks are chosen and prepared by the host country.

9

The marks available for each problem are defined by the organizer of the competition, but the total number of points for the theoretical problems should be 30 and for the experimental 20 The laboratory problems should consist of theoretical analysis (plan and discussion) and experimental execution.

The winners will receive diplomas or honourable mentions in accordance with the number of points accumulated as follows:

> The mean number of points accumulated by the three best participants is considered as 100%

The contestants who accumulate more than 90% of points receive first prize (diploma).

The contestants who accumulate more than 78% up to 89% receive second prize (diploma).

The contestants who accumulate more than 65% up to 77% receive third prize (diploma).

The contestants who accumulate more than 50% up to 64% receive an honourable mention.

The contestants who accumulate less than 50% of points receive certificates of participation in the competition.

The mentioned marks corresponding to 90%, 78%, 65% and 50% should be calculated by rounding off to the nearest lower integers.

The participant who obtains the highest score will receive a special prize and diploma.

Special prizes can be awarded.

Formal recognition in the form of certificates can be given to the secondary school teachers of the International Physics Olympiad students. The list of the teachers (one per each student) to be recognized should be given to the organizers by the team leaders not later than on the arrival of the team.

10

The obligations of the organizer:

a) The organizer is obliged to ensure that the competition is conducted in accordance with the Statutes.

b) The organizer should produce a set of "Organization Rules," based on the Statutes, and send them to the participating countries in good time. These Organization Rules shall give details of the Olympiad not covered in the Statutes, and give names and addresses of the institutions and persons responsible for the Olympiad.

c) The organizer establishes a precise program for the competition (schedule for the contestants and the accompanying persons, program of excursions, etc.), which is sent to the participating countries in advance.

d) The organizer should check immediately after the arrival of each delegation whether its contestants meet the conditions of the competitions.

e) The organizer chooses (according to #7 and the list of physics contents in the Appendix to these Statutes) the problems and ensures their proper formulation in English and in other languages set out in #5. It is advisable to select problems where the solutions require a certain creative capability and a considerable level of knowledge. Everyone taking part in the preparation of the competition problems is obliged to preserve complete secrecy

f) The organizer must provide the teams with interpreters.

g) The organizer should provide the delegation leaders with photostat copies of the solutions of the contestants in their delegation before the final classification

h) The organizer is responsible for the grading of the problem solutions.

i) The organizer drafts a list of participants proposed as winners of the prizes and honourable mentions.

k) The organizer prepares the prizes (diplomas), honourable mentions and awards for the winners of the competition.

11

The scientific part of the competition must be within the competence of the International Board, which includes the delegation heads and pedagogical leaders of all the delegations.

The Board is chaired by a representative of the organizing country. He or she is responsible for the preparation of the competition and serves on the Board in addition to the accompanying persons of the respective teams.

Decisions are passed by a majority vote. In the case of equal numbers of votes for and against, the chairman has the casting vote.

12

The delegation leaders are responsible for the proper translation of the problems from English or other languages mentioned in # 5 to the mother tongue of the participants.

13

The International Board has the following responsibilities:

a) to direct the competition and supervise that it is conducted according to the regulations;

b) to ascertain, after the arrival of the competing teams, that all their members meet the requirements of the competition in all aspects. The Board will disqualify those contestants who do not meet the stipulated conditions. The costs incurred by a disqualified contestant are covered by his or her country;.

c) to discuss the Organizers' choice of tasks, their solutions and the suggested evaluation guidelines before each part of the competition. The Board is authorized to change or reject suggested tasks but not to propose new ones. Changes may not affect experimental equipment. There will be a final decision on the formulation of tasks and on the evaluation guidelines. The participants in the meeting of the International Board are bound to preserve secrecy concerning the tasks and to be of no assistance to any of the participants,

d) to ensure correct and just classification of the prize winners; the grading of those contestants who do not receive prizes or honourable mentions is not to be disclosed;

e) to establish the winners of the competition and make a decision concerning presentation of the prizes and honourable mentions. The decision of the International Board is final;

f) to review the results of the competition.

g) to select the country which will be assigned the organization of the next competition.

Observers may be present at the meetings of the International Board, but not to vote or take part in the discussion.

 # 14

The institution in charge of the Olympiad announces the results and presents the awards and diplomas to the winners at an official gala ceremony. It invites representatives of the organizing Ministry and scientific institutions to the closing ceremony of the competition.

 # 15

The long term work involved in organizing the Olympiads is coordinated by a "Secretariat for the International Physics Olympiads". This Secretariat consists of a Secretary and Vice-Secretary normally from the same country. They are elected by the International Board for a period of five years when the chairs become vacant.

 # 16

The present Statutes have been drafted on the basis of experience gained during past international competitions.

Changes in these Statutes, the insertion of new paragraphs or exclusion of old ones, can only be made by the International Board and require a qualified majority (2/3 of the votes).

No changes may be made to these Statutes or Syllabus unless each delegation obtained written text of the proposal at least three months in advance.

 # 17

Participation in an International Physics Olympiad signifies acceptance of the present Statutes by the Education Ministry of the participating country.

 # 18

The originals of these Statutes are written in English.

The Syllabus

General

Adopted in Portoroz, Yugoslavia, June 1985
Modified in: Warsaw, Poland, July 1989
Havana, Cuba, July 1991

a) The extensive use of the calculus (differentiation and integration) and the use of complex numbers or solving differential equations should not be required to solve the theoretical and practical problems.

b) Questions may contain concepts and phenomena not contained in the Syllabus but sufficient information must be given in the questions so that candidates without previous knowledge of these topics would not be at a disadvantage.

c) Sophisticated practical equipment likely to be unfamiliar to the candidates should not dominate a problem. If such dev ces are used then careful instructions must be given to the candidates.

d) The original texts of the problems have to be set in the SI units.

A. Theoretical Part

Adopted in Portoroz, Yugoslavia, June 1985
Modified in Warsaw, Poland, July 1989

The first column contains the main entries while the second column contains comments and remarks if necessary.

1. Mechanics

a) Foundation of kinematics of a point mass	Vector description of the position of a point mass, velocity and acceleration as vectors
b) Newton's laws, inertial systems	Problems may be set on changing mass
c) Closed and open systems, momentum and energy, work, power	

d) Conservation of energy, conservation of linear momentum, impulse	
e) Elastic forces, frictional forces, the law of gravitation, potential energy and work in a gravitational field	Hooke's law, coefficient of friction (F/R = const), frictional forces static and kinetic, choice of zero of potential energy
f) Centripetal acceleration, Kepler's laws	

2. Mechanics of Rigid Bodies

a) Statics, center of mass, torque	Couples, conditions of equilibrium of bodies
b) Motion of rigid bodies, translation, rotation, angular velocity, angular acceleration, conservation of angular momentum	Conservation of angular momentum about fixed axis only
c) External and internal forces, equation of motion of a rigid body around the fixed axis, moment of inertia, kinetic energy of a rotating body	Parallel axes theorem (Steiner's theorem) additivity of the moment of inertia
d) Accelerated reference systems, inertial forces	Knowledge of the Coriolis force formula is not required

3. Hydromechanics

No specific questions will be set on this but students would be expected to know the elementary concepts of pressure, buoyancy and the continuity law.

4. Thermodynamics and Molecular Physics

a) Internal energy, work and heat, first and second laws of thermodynamics	Thermal equilibrium, quantities depending on state and quantities depending on process
b) Model of a perfect gas, pressure and molecular kinetic energy, Avogadro's number, equation of state of a perfect gas, absolute temperature	Also molecular approach to such simple phenomena in liquids and solids as boiling, melting etc

c) Work done by an expanding gas limited to isothermal and adiabatic processes	Proof of the equation of the adiabatic process is not required
d) The Carnot cycle, thermodynamic efficiency, reversible and irreversible processes, entropy (statistical approach), Boltzmann factor	Entropy as a path independent function, entropy changes and reversibility, quasistatic processes

5. Oscillations and waves

a) Harmonic oscillations, equation of harmonic oscillation	Solution of the equation for harmonic motion, attenuation and resonance — qualitatively
b) Harmonic waves, propagation of waves, transverse and longitudinal waves, linear polarization, the classical Doppler effect, sound waves	Displacement in a progressive wave and understanding of graphical representation of the wave, measurements of velocity of sound and light, Doppler effect in one dimension only, propagation of waves in homogeneous and isotropic media, reflection and refraction, Fermats principle
c) Superposition of harmonic waves, coherent waves, interference, beats, standing waves	Realization that intensity of wave is proportional to the square of its amplitude. Fourier analysis is not required but candidates should have some understanding that complex waves can be made from addition of simple sinusoidal waves of different frequencies. Interference due to thin films and other simple systems (final formulae are not required), superposition of waves from secondary sources (diffraction)

6. Electric Charge and Electric Field

a) Conservation of charge, Coulomb's law	
b) Electric field, potential, Gauss' law	Gauss' law confined to simple symmetric systems like sphere, cylinder, plate etc., electric dipole moment
c) Capacitors, capacitance, dielectric constant, energy density of electric field	

7. Current and Magnetic Field

a) Current, resistance, internal resistance of source, Ohm's law, Kirchhoff's laws, work and power of direct and alternating currents, Joule's law	Simple cases of circuits containing non-ohmic devices with known V-I characteristic
b) Magnetic field (B) of a current, current in a magnetic field, Lorentz force	Particles in a magnetic field, simple applications like cyclotron, magnetic dipole moment
c) Ampere's law	Magnetic field of simple symmetric systems like straight wire, circular loop and long solenoid
d) Law of electromagnetic induction, magnetic flux, Lenz's law, self-induction, inductance, permeability, energy density of magnetic field	
e) Alternating current, resistors, inductors and capacitors in AC-circuits, voltage and current (parallel and series) resonances	Simple AC-circuits, time constants, final formulae for parameters of concrete resonance circuits are not required

8. Electromagnetic waves

a) Oscillatory circuit, frequency of oscillations, generation by feedback and resonance

b) Wave optics, diffraction from one and two slits, diffraction grating, resolving power of a grating, Bragg reflection,	
c) Dispersion and diffraction spectra, line spectra of gases	
d) Electromagnetic waves as transverse waves, polarization by reflection, polarizers	Superposition of polarized waves
e) Resolving power of imaging systems	
f) Black body, Stefan-Boltzmann law	Planck's formula is not required

9. Quantum Physics

a) Photoelectric effect, energy and impulse of the photon	Einstein's formula is required
b) De Broglie wavelength, Heisenberg's uncertainty principle	

10. Relativity

a) Principle of relativity, addition of velocities, relativistic Doppler effect

b) Relativistic equation of motion, momentum, energy, relation between energy and mass, conservation of energy and momentum

11. Matter

a) Simple applications of the Bragg equation

b) Energy levels of atoms and molecules (qualitatively), emission, absorption, spectrum of hydrogenlike atoms

c) Energy levels of nuclei (qualitatively), alpha-, beta- and gamma-decays, absorption of radiation, halflife and exponential decay, components of nuclei, mass defect, nuclear reactions

B. Practical Part

(Adopted in London-Harrow, United Kingdom, July 1986)

The Theoretical Part of the Syllabus provides the basis for all the experimental problems. The experimental problems given in the experimental contest should contain measurements.

Additional requirements.

1. Candidates must be aware that instruments affect measurements.

2. Knowledge of the most common experimental techniques for measuring physical quantities mentioned in Part A

3. Knowledge of commonly used simple laboratory instruments and devices such as calipers, thermometers, simple volt-, ohm- and ammeters, potentiometers, diodes, transistors, simple optical devices and so on

4. Ability to use, with the help of proper instruction, some sophisticated instruments and devices such as double-beam oscilloscope, counter, ratemeter, signal and function generators, analog-to-digital converter connected to a computer, amplifier, integrator, differentiator, power supply, universal (analog and digital) volt-, ohm- and ammeters

5. Proper identification of error sources and estimation of their influence on the final result(s).

6. Absolute and relative errors, accuracy of measuring instruments, error of a single measurement, error of a series of measurements, error of a quantity given as a function of measured quantities

7. Transformation of a dependence to the linear form by appropriate choice of variables and fitting a straight line to experimental points.

8. Proper use of graph paper with different scales (for example polar and logarithmic papers)

9. Correct rounding off and expressing the final result(s) and error(s) with correct number of significant digits

10. Standard knowledge of safety in laboratory work. (Nevertheless, if the experimental set-up contains any safety hazards the appropriate warnings should be included into the text of the problem.)

Participation in the International Physics Olympiads

Olympiad	1	2	3	4	5	6	7	8	9	1... 0	1	2	3	4	5	6	7	8	9	2... 0	1	2	3	4
Year	196... 7	8	9	197... 0	1	2	4	5	6	7	9	198... 1	2	3	4	5	6	7	8	9	199... 0	1	2	3
States:																								
1. Argentina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O
2. Australia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#	#	#	#
3. Austria	-	-	-	-	-	-	-	-	-	-	-	-	#	#	#	#	#	#	H	#	#	#	#	#
4. Belgium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#	#	#
5. Bohemia	<	see: Czecho-Slovakia (below)														>								#
6. Bulgaria	#	#	#	#	H	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#	#	#
7. Canada	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#	#	#	#	#	#
8. China	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	O	#	#	#	#	#	#	#	#
9 Colombia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#	#	#
10. Croatia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#
11. Cuba	-	-	-	-	-	#	-	-	-	-	-	-		#	#	#	#	#	#	#	#	H	#	#
12. Cyprus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#	#	#	#	#
13. Denmark	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	-	-	-	-	-
14. Estonia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#
15. Finland	-	-	-	-	-	-	-	O	#	#	#	#	#	#	#	#	#	#	#	#	#	#	H	#
16. France	-	-	-	-	-	#	-	#	#	#	-	#	#	#	-	-	-	-	-	-	-	-	-	-
17. FRG	-	-	-	-	-	-	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#	#
18. Great Britain	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	H	#	#	#	#	#	#	#
19. Greece	-	-	-	-	-	-	-	-	-	-	-	-	#	-	-	-	-	O	-	O	-	#	#	#
20. Hungary	#	H	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
21. Iceland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#	#	#	#	#	#	#	#	#
22. Indonesia	-	-	-	-	-	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	#
23. Iran	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#	U
24. Israel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O
25. Italy	-	-	-	-	-	-	-	-	-	-	-	#	#	-	-	O	-	#	#	#	#	#	#	#
26 Kuwait	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	O	#	#	#	#	-	#	#
27. Lithuania	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	U	O	-	#	#
28. Mexico	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#
29. Netherlands	-	-	-	-	-	-	-	-	-	-	-	-	#	#	#	#	#	#	#	#	H	#	#	#
30. Norway	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#	#	#	#	#	#	#	#	#
31. Philippines	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#
32 Poland	H	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#	#	#	H	#	#	#	#
33. Portugal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O
34. Romania	#	#	#	#	#	H	#	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#

Olympiad									1...										2.					
	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4
Year	196...			197...								198...								199..				
	7	8	9	0	1	2	4	5	6	7	9	1	2	3	4	5	6	7	8	9	0	1	2	3
States:																								
35. Russia	< see: Soviet Union (below) >																						#	#
36. Singapore	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	W	#	#	#	#	#
37. Slovakia	< see: Czecho-Slovakia (below) >																							#
38. Slovenia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#
39. South Korea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#
40. Spain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	O	#	#	#	#
41. Suriname	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#
42. Sweden	-	-	-	-	-	O	-	-	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#
43. Taiwan Ch	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O
44. Thailand	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#
45. Turkey	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#	#	-	#	#	#	#	#
46. Ukraine	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	#	#
47. UAE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	-	-	-	-
48. USA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	#	#	#	#	#	#	#	H
49. Vietnam	-	-	-	-	-	-	-	-	-	-	-	#	#	#	#	#	-	#	#	-	#	-	#	#
50. Yugoslavia	< see: SFR Yugoslavia (below) >																						S	S
Former states:																								
1. Czecho-Slovak	#	#	H	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#	#	#	#	<dissolved>
2. GDR	-	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	H	#	#	#	<joined to FRG>		
3. Soviet Union	-	#	#	H	#	#	#	#	#	#	H	#	#	#	#	#	#	#	#	#	#	#	<dissolved>	
4. SFR Yugoslavia	-	#	#	#	-	-	-	-	-	#	#	#	#	#	#	H	#	#	#	#	#	#	<dissolved>	
International organizations:																								
1. UNESCO	-	O	-	-		-	-	-	-	-	-	O	-	-	-	-	O	O	O	-	-	O	-	-
2. EPS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	O	O	O	O	O	O	O	O	O	O

Explanation:

- \# : participation
- \- : no participation
- H : host country
- O : observer
- W : willingness to start from next year declared
- U : unofficial participation (guest of the organizers)
- S : sanctions of the UN (no participation)

Organizers of the International Physics Olympiads

Past:

I	1967	Warsaw (Poland)
II	1968	Budapest (Hungary)
III	1969	Brno (Czecho-Slovakia)
IV	1970	Moscow (Soviet Union)
V	1971	Sofia (Bulgaria)
VI	1972	Bucharest (Romania)
VII	1974	Warsaw (Poland)
VIII	1975	Guestrow (GDR)
IX	1976	Budapest (Hungary)
X	1977	Hradec Kralove (Czecho-Slovakia)
XI	1979	Moscow (Soviet Union)
XII	1981	Varna (Bulgaria)
XIII	1982	Malente (FRG)
XIV	1983	Bucharest (Romania)
XV	1984	Sigtuna (Sweden)
XVI	1985	Portoroz (Yugoslavia)
XVII	1986	London-Harrow (United Kingdom)
XVIII	1987	Jena (GDR)
XIX	1988	Bad Ischl (Austria)
XX	1989	Warsaw (Poland)
XXI	1990	Groningen (The Netherlands)
XXII	1991	Havana (Cuba)
XXIII	1992	Helsinki (Finland)
XXIV	1993	Williamsburg (USA)

Future:

XXV	1994	Beijing (China) - invitation made
XXVI	1995	Canberra (Australia) - confirmed
XXVII	1996	(*) (Norway) - confirmed
XXVIII	1997	Sudbury (Canada) - confirmed
XXIX	1998	(*) (Iceland) - confirmed
XXX	1999	(*) (Italy) - not confirmed
XXXI	2000	(*) (United Kingdom) - confirmed
XXXII	2001	(*) Turkey - confirmed
XXXIII	2002	Belgium - preliminary contacts

(the asterisk (*) denotes that the site of the competition will be determined later)